Decision Analysis of Restoration Actions for Faunal Conservation and Other Stakeholder Values: Dauphin Island, Alabama

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Introduction

Dauphin Island is a barrier island located in the northern Gulf of Mexico and serves as the only barrier island providing protection to much of the State of Alabama's coastal natural resources. The ecosystem spans over 3,500 acres of barrier island habitat including, beach, dune, overwash fans, intertidal wetlands, maritime forest and freshwater ponds. In addition, Dauphin Island provides protection to approximately one-third of the Mississippi Sound estuarine habitats in its lee including oyster reefs, mainland marshes and seagrasses. The habitat supports a variety of species including at least 347 species of birds, some of which are Federally or State listed species that either pass through or reside on the island. The island enhances the region's recreational and commercial fishery habitat through maintenance and protection of water quality in the sound and adjacent nearshore habitats. Dauphin Island also serves as the location for cultural resources, the United States Air Force's (USAF) early warning radar station, the State's marine education facilities, infrastructure for the oil and gas industry, and a vibrant tourism economy. Consequently, anthropogenic actions (e.g., structural changes) and externally driven natural factors (e.g., storms and sea level rise) that impact Dauphin Island could affect both the conservation and economic value of the island.

Restoration of Dauphin Island may help enhance, maintain, and protect significant coastal habitat and living resources damaged by the Deepwater Horizon (DWH) oil spill and recent tropical cyclones. Therefore, the goal of the Alabama Barrier Island Restoration Assessment project (ALBIRA) was to investigate viable options for the restoration of Dauphin Island. Restoration measures considered were those intended to reduce damage and restore 1) island resources, including habitat and living coastal and marine resources, and 2) coastal resources of the Mississippi Sound and Mobile Bay and the southern portion of Mobile County, including the expansive Heron Bay wetlands. The likelihood of restoration success can be maximized by ensuring that restoration plans include an understanding of the island's historical geomorphological evolution, physical topography and bathymetry, and geologic and oceanographic factors. A primary objective of the present study was to scientifically predict future island conditions consequent to multiple restoration alternatives using technical modeling and subsequent decision analysis in the face of uncertain climate conditions. Decision analysis refers to a formal framework for using visual, systematic, and quantitative assessments to evaluate choices in complex problem situations (Clemen 1997).

Major uncertainties in restoration project planning and design center largely around climate change, relative sea level rise, and how the system will respond to these changes over time. To reduce this uncertainty, climate change and sea level rise scenarios were integrated in various technical analyses during ALBIRA to assess sustainability of potential future restoration measures (USACE et al. 2020). This could help inform decision-makers as to the risk of implementation of restoration measures with respect to changing climatic conditions.

We applied a structured decision-making (SDM) framework to predict the consequences of various restoration measures on Dauphin Island designed to ensure island sustainability, ecosystem integrity and reduce damages of natural resources (Conroy and Peterson 2013; Dalyander et al. 2016). The decision analysis required integration of technical expertise, model results and appropriate stakeholder objectives to determine the optimal alternative or sets of alternatives for restoration of Dauphin Island. This SDM framework was integrated within the investigation of sustainable options through the ALBIRA feasibility study. Based on science, technical expertise and evaluation the framework facilitated effective evaluation of the benefits and impacts of different restoration measures. ALBIRA was conducted by a large team of United States Geological Survey (USGS) and United States Army Corps of Engineers (USACE) scientists and engineers and included modeling the island to evaluate the most resilient and sustainable island restoration (e.g., sand placement) or land acquisition activities and configurations in support of critical habitats and resources. Figure 1 depicts the flow of data products that were used for parameterization of the decision model (USACE et al. 2020). To accurately develop this modeling and technical evaluation, fieldwork, data collection, and analyses (e.g., topography, bathymetry, habitat mapping) were conducted by various members of the larger team and alternatives for restoration were developed using the appropriate science so that the alternatives could be evaluated using decision analysis. The ultimate goal of the decision analysis was to determine the consequences of restoration actions on a suite of stakeholder objectives. Our objectives were:

1) to use decision science to determine objectives associated with the long-term sustainability and resiliency of the state of Alabama's only barrier island, its habitats, the living coastal and marine resources it supports, as well as estuarine conditions in Mississippi Sound and the extensive coastal wetlands to the north.

2) to develop a decision tool with input from decision makers (e.g., Alabama Department of Conservation and Natural Resources) that constituted a transparent assessment of tradeoffs among the restoration strategies.

Decision Analysis Framework

Assessment of restoration alternatives is difficult when stakeholders have both multiple objectives and different values that impact judgement about expectations related to management goals (Keeney and Raiffa 1993). Temporal variations in the benefits associated with restoration actions may add further uncertainty to the decision process, but are often not taken into consideration (Guerrero et al. 2017). Multiple, conflicting objectives can be assessed using decision science which can also account for various forms of uncertainty, risk tolerance, and external drivers such as climate (Keeney and Rafia 1993; Wilson and McDaniels 2007; Conroy and Peterson 2013). SDM is a framework that has been employed in the field of restoration ecology to deliberatively decompose complexity related to decisions (Failing et al. 2013; Martin et al. 2018). SDM processes define the problem and stakeholder values (i.e., objectives), identify potential alternatives for restoration, model the consequences of the alternatives on the objectives, and evaluate trade-offs among the potential decisions (Conroy and Peterson 2013; Gregory et al. 2012).

The problem context for Dauphin Island was defined by stakeholders to identify restoration actions that would best satisfy social, economic and ecological values associated with the island. The model domain included in the decision framework in the present study was described by Enwright et al. (2020) and included an initial 2015 island morphology (~ 15.8 km^2) and water bathymetry extending 2.5 km from the historic shorelines, 1940-2015, of the island. See Enwright et al. (2020) for more details. Another aspect of the model domain in the present study is that modeling scenarios were often constrained to the east or west end of Dauphin Island to evaluate specific values in the different areas.

Stakeholder Objectives

Once the problem was framed, the next step in the SDM was to define stakeholder objectives so that alternatives that may help achieve the objectives could be identified. Objectives were compiled and elicited from stakeholders and experts as well as from public surveys, reports, and in group consultation settings. These sources included the Alabama Coastal Comprehensive Plan (ACCP; USACE 2016) and the ongoing Dauphin Island Watershed Study (Mobile Bay National Estuarine Program; MBNEP 2016) to inform the structure of the objectives. For example, the USACE conducted scoping sessions with the public to identify high level objectives surrounding coastal and living natural resources, and those objectives were published on-line in a spatially explicit context (ACCP Map; http://www.sam.usace.army.mil/Missions/Program-and-Project-Management/Alabama-Coastal-Comprehensive-Plan/). In addition, experts from the USACE coastal management team and the State of Alabama Lands Division met to discuss Dauphin Island specific objectives and how they would ultimately be related to restoration actions. Panels of faunal experts from academia, State and Federal partners, Non-Governmental Organizations, and private consultants were convened to develop objectives related to cultural and living natural resources.

The following stakeholder-identified objectives were established:

1) maximize ecological function and physical processes (i.e., sustainability)
2) minimize social impacts and costs
3) maximize coastal and marine resources
4) minimize time that it would take for a restoration action to provide benefits for the island

Development of Alternatives

Alternative restoration actions (i.e., measures) fell into two groups; natural and nature-based feature alternatives—such as sand placement, sand bypassing, and/or marsh restoration—and land acquisition actions where individual parcels could be purchased for conservation value.

Detailed descriptions can be found in the ALBIRA interim and final reports (USGS et al. 2017; USACE et al. 2020); a summaries of the alternatives are reported in Tables 1 and 2.

Modeling the Consequences of the Alternatives on the Objectives

Once the stakeholder-identified objectives were established, we used them in the development of a decision support model to assist stakeholders evaluating the decisions related to restoration of Dauphin Island. To conduct the decision analysis, we followed the basic steps outlined by Clemen (1997): 1) formed causal relations among restoration alternatives and system response; 2) constructed a basic model outlining these relations; 3) parameterized the model; 4) determined the optimal decision from the model results; and 5) conducted sensitivity analysis to determine which components of the model had the greatest influence on the decision. Output from multiple studies (Enwright et al. 2020; Gonzalez et al. 2020; Mickey et al. 2020) as well as expert knowledge was integrated into the decision analysis.

For step 1, we identified state variables and drafted an influence diagram. State variables constituted measurable attributes that were important for describing relations among outcomes representing the objectives and alternative options (i.e, measures). These variables were identified by scientists, decision makers and other appropriate stakeholders or technical experts over the course of the project through consultations to inform the framework of the decision analysis. These consultations were either face-to-face, facilitated webinars, or via email with specific elicitation goals (usually in spreadsheet form; Appendix A).

The decision framework was represented by the draft influence diagram which was presented in an interim report (USGS et al. 2017). Influence diagrams are graphical depictions of the causal relations among problem components (Conroy and Peterson 2013. The influence diagram for ALBIRA depicted relations among stakeholder objectives, state variables and alternatives (Figure 2; Conroy and Peterson 2013).

Using the influence diagram as the framework, we addressed steps 2 and 3 by developing two Bayesian belief networks (BBNs) and consequent decision support models (Figures 3 and 4) using Netica (version 1.12, Norsys Software Corporation, Vancouver, British Columbia). The BBNs and decision support models were used to evaluate the impacts of restoration options on stakeholder objectives and to evaluate tradeoffs among restoration measures.

BBN are graphical models of complex systems that are useful in evaluation of natural resource restoration problems (Stewart-Koster et al. 2010; Gieder et al. 2014). BBNs are directed acyclic graphs comprised by networks of nodes that represent key components of a system connected with one directional links (arcs) indicating conditional dependencies (Pourret et al. 2008). Influencing factors (parent nodes) are connected to influenced factors (child nodes) and the network is quantified by parameterizing conditional probability tables (CPTs) for nodes in the network. Inputs to the CPTs can be informed by experts or available data and BBNs can evaluate the independent and conditional (interactive) effects of environmental change or variation on the modeled response variables (Pourret et al. 2008; Conroy and Peterson 2013). By including the probabilities of the parent nodes in a BBN, the probabilities in the child nodes are calculated by belief updating. When a particular state of a parent node is observed, probabilities in the child nodes ($P(Y \backslash X = x$) are estimated using Bayes Theorem:

$$P(y \backslash x) = \frac{P(y \backslash x)P(y)}{P(x)}$$

where $P(y)$ is the prior probability of the child node and $P(x)$ is a normalizing constant. Prior probabilities can be populated into CPTs from multiple sources making BBNs flexible models that can incorporate expert opinion and data, either together or separately to inform (parameterize) the network. In addition, decision nodes with states that represent the possible restoration actions or land purchase (in the case discussed here) can be added to the network along with costs and benefits of actions. Finally, utility nodes that express the expected value or utility of decisions on the modeled variables can be included to assist with analysis (Conroy and Peterson 2013).

Bayesian Belief Network Nodes

To address step 4, individual BBNs were constructed to predict the utility of implementing 1) structural restoration measures (Figure 3) and 2) land acquisition options (Figure 4; Marcot et al. 2006). Each BBN consisted of decision, nature (state variables), and utility (value) nodes that modeled conditional probabilities related to the influence of decisions (restoration measures or land purchase) on discrete system states (nature nodes; representing system states), and thereby predicted the additive stakeholder utility (value) associated with potential restoration actions. Decision nodes were parameterized with individual alternative restoration measures (Tables 1 and 2). In practice, relations among nature nodes were modeled using probabilistic dependencies derived from empirical data and expert opinion. For each nature (i.e., uncertainty node) node CPTs were populated with probabilities of causal links among associated nodes (see Figure 5 example CPT). Different states within nature nodes were parameterized with data generated from multiple sources during ALBIRA (i.e., Enwright et al. 2020; Mickey et al. 2020; specific sources are cited below). Conditional probabilities for each state of related nodes also varied depending on the restoration models and four different storm and sea level rise scenarios (ST/SL scenarios) that impacted island morphology and habitat composition. Utility nodes were parameterized with data derived from expert opinion or data derived from linked nodes and were reflective of values, as costs or benefits, associated with outcomes or decisions. The utility nodes were equally-weighted and the optimal decision was the measure, or multiple measures, with the highest sum of the utility values in the network. Descriptions of each model component (hereafter, node) represented in the model, as well as the data source for each node, are presented below.

Decision Nodes

Each BBN had one decision node that included the primary sets of alternative restoration measures (blue rectangles, Figures 3 and 4) which were related to sand placement (beach and dune nourishment/restoration), sand bypassing, and marsh restoration (Table 1) and land acquisition (Table 2). Alternatives that involved structural restoration actions or no action were included in the Measures decision node in one BBN (Figure 3); whereas, non-structural alternatives that involved the purchasing of property were included in the Land Acquisition decision node in a separate BBN (Figure 4). These alternatives are described in more detail in (USGS et al. 2017; USACE et al. 2020).

Nature and Utility Nodes

Relations among the nature nodes (yellow rectangles; Figures 3 and 4) were represented by causal links and a CPT for each was populated with probabilities or dependencies of relations among associated nodes. There were 33 nature nodes included in the restoration BBN and one nature node (informed with multiple attributes) in the land acquisition BBN; they were parameterized using either data generated from other studies in ALBIRA or by experts and are listed and described below. The organization of the text and tables attempts to follow causal links in the two BBNs that inform the five equally weighted utility nodes in the restoration measures BBN and two equally weighted utility nodes in the land acquisition BBN.

Model Scenarios

Model scenarios were developed by USACE and USGS; the model domains for each represented either single restoration measures or a combination of multiple restoration measures (see Table 3). Mickey et al. (2020; Table 1, Page 3) and Enwright et al. (2020; Table A3, Page 11) describe the modeling scenarios which they used to forecast the morphologic evolution and changes in terrestrial and submerged habitats for four ST (storminess) and SL (sea level rise) scenarios (see below) over a decade for Dauphin Island under future no-action options (R0) and different restoration models (R1-R7 in Mickey et al. 2020 and R2-R7 in Enwright et al. 2020). In Mickey et al. (2020) and Enwright et al. (2020), R0 and R4 were whole island models. Data from these models were output to east and west end spatial extents of Dauphin Island and used to calculate associated habitat changes for those areas associated with two R0 and two R4 scenarios in the BBN. This was accomplished by clipping the relevant spatially explicit model output for habitat composition using the spatial analysis tool in ArcGIS Pro 2.4.3 (Redlands, California) to account for spatially explicit restoration measures located on the east or west end of the island. The west end was defined as the area west of where Pelican Island welds to Dauphin Island; the model domains of the west and east end were similar in size (~ 692 ha for east and 667 ha for west). An additional restoration model scenario, R8, was also included in this BBN node and incorporated measure 18, (West End Back-Barrier Herbaceous Dune Plant Restoration; Table 3). Associated habitat data were incorporated from the R0 model scenario. The model scenarios node linked the restoration alternatives listed in the Measures decision node to the modeled outcomes in habitat composition, water depth, and habitat suitability indices (HSI) for oysters and seagrass (HSI Seagrass, HSI Oyster) nodes.

Storm and Sea Level Rise Scenarios

Four storm and sea level rise scenarios were developed and used in ALBIRA by USACE and USGS (Figure A3, Page 10; Table A3 Page 11 in Enwright et al. 2020) to predict changes in island morphology, adjacent marine habitat bathymetry and associated island habitats (Enwright et al. 2020; Mickey et al. 2020). These scenarios (described below) depicted various combinations of severity and rates of storminess (ST) and sea level rise (SL) conditions (Table 4) including:

- ST2SL1H – medium number of storms in a decade (ST2), sea level rise of 0.3 m (SL1) by 2030 [USACE high curve],
- ST2SL1I – medium number of storms in a decade (ST2), sea level rise of 0.3 m (SL1) by 2050 [USACE intermediate curve],
- ST3SL3H – high number of storms in a decade (ST3), sea level rise of 1.0 m (SL3) by 2070 [USACE high curve], and
- ST3SL3I – high number of storms in a decade (ST3), sea level rise of 1.0 m (SL3) by 2128 [USACE intermediate curve].

To include the effects of ST/SL scenarios on restoration decisions in the BBN, we calculated the estimated probability of each scenario occurring over the timeframe that was modeled in ALBIRA; 10 years was the model domain for geomorphology and habitat models. To do this we used information available through USACE and USGS models and tools documented in Gonzalez et al. (2020) and Mickey et al. (2020). In addition, we included information from Sweet et al. (2017).

Estimated probabilities for the storm portion of the scenarios were determined using statistical methods detailed in Gonzalez et al. (2020) and Mickey et al. (2020). In all, four levels of storminess were computed based on the island response obtained with a 1-dimensional morphology model framework, of which two levels were used in the evaluation of potential restoration measures. ST2 had an estimated 57% probability that the scenario would occur during the 10 year model horizon and ST3 had an estimated 29% probability that the scenario would occur over the same timeframe (See Mickey et al. 2020, Table 2, Page 15).

Sea level rise scenarios for ALBIRA were based on the USACE sea level change calculator (USACE 2019; Version 2019.21; http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html) for intermediate and high rate curves using the National Oceanic Atmospheric Association's (NOAA) Dauphin Island tide gage (8735180; NOAA 2019; https://tidesandcurrents.noaa.gov/stationhome.html?id=8735180) which estimated a 0.7 m and a 1.7 m rise in sea level by the year 2100 for intermediate and high rate curves, respectively (Figure 6). There were no estimated probabilities to predict the likelihood of the sea level scenarios; however, NOAA (i.e., Sweet et al. 2017) compiled predicted probabilities of sea level rise under several greenhouse gas scenarios (Figure 7).

The regional scenario based on historic conditions and predicted relative sea level rise for Dauphin Island was retrieved from NOAA (2019; https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?plot=scenario&id=8735180#tab50yr). A regional sea level rise curve was identified that best represented the sea level rise for each ST/SR scenario modeled in ALBIRA (Figure 7). We located each of the four ALBIRA sea level scenarios included in the restoration models (intersection of labeled vertical lines and horizontal lines; Figure 7) relative to predicted sea level rise curves estimated by Sweet et al. (2017) based on moderate representative concentration pathways (RCP) of greenhouse gases [(RCP4.5 W/m^2 (watt per square meter, units for solar irradiance; van Vuuren et al. 2011); Sweet et al. 2017, Table 4, Page 22)]. ST2SL1H, with an estimated sea level rise of 0.3m (SL1) by 2030, was closest to the intermediate-high (yellow) curve with an estimated exceedance probability of 0.05%. ST2SL1I, with an estimated sea level rise of 0.3m (SL1) by 2050, was closely aligned to the intermediate low (light blue) curve with an exceedance probability of occurrence of 73%. ST3SL3H, with estimated sea level rise of 1.0m (SL1) by 2070, was also closely aligned to the intermediate-high (yellow) curve with an estimated exceedance probability of 73%. Because the year 2128 (for ST3SL3I) was not included on the graph obtained from NOAA, we extended the NOAA curves to include the years 2100-2140 based on the sea level rise rate estimates for 2080-2100. We then visualized that the ST3SL3I, with an estimated sea level rise of 1.0m (SL1) scenario was closest to the intermediate-low (light blue) curve with an exceedance probability of 0.05% (Table 4).

To obtain the final likelihoods associated with each ST/SL scenario, the total probability for each ST/SL scenario was estimated by multiplying the ST probabilities [(P_{st} in the equation below) from Mickey et al. 2020, Table 2, Page 15)] and SL probabilities for the closest fit NOAA models for RCP4.5 [(P_{sl} in the equation below) from Sweet et al. 2017; our Table 4)]. The probability estimates were normalized by summing the resulting probabilities (0.6321; Table 4), dividing the product of each scenario by the sum and multiplying the value by 100, or

$$\frac{(P_{st} \times P_{sl})}{\sum(P_{st} \times P_{sl})} * 100$$

The normalized probabilities were input into the BBN for each ST/SL scenario as likelihoods associated with each state (Table 4).

Habitat Composition

The proportion of the total area of Dauphin Island comprised of each habitat class excluding marine and estuarine water (intertidal flat, intertidal beach, marsh, beach, dune, barrier flat, woody vegetation, woody wetland, and fresh water) for year 10 (Y10) of 10 year simulations (Y10) was calculated based on data provided by Enwright et al. (2020; Tables A6-A9, Pages 17-20). They predicted habitat composition for the future no-action options and six other model scenarios (R2-R7) for the four ST/SL scenarios. For the BBN, we spatially split R0 and R4 to separately model the east and west spatial extent of Dauphin Island (R0 East End, R0 West End; R4 M5 West End WOBO, R4 East End Dune). See the Model Scenario description (above) for methods. In the BBN, we also included the R8 scenario (Measure 18). Total area (hectares; ha) of the model domain for each restoration model scenario and ST/SL run at Y10 was computed by adding the areas of individual habitat types. The frequency distribution of each habitat class was then calculated as the area of habitat in each class (x) divided by the total area (ha). To satisfy the rules for the CPT the quotient was multiplied by 100, or

$$\frac{area\ habitat\ x}{total\ area} * 100$$

The results from these calculations were entered as a probability distribution for habitat types totaling to 100 percent for each model and ST/SL scenario combination in the BBN (Table 5; Figure 5).

Habitat Delta

Habitat delta reflects the percent change in area for each habitat type for each model and ST/SL scenario between year 0 (Y0) to year 10 (Y10); data are from simulations reported in Enwright et al. (2020; Tables A6-A9, Pages 17-20). For each individual habitat type (x) we calculated the percent change in area predicted in Y10 minus the area in Y0, divided by the total habitat area in Y0 and multiplied by 100, or

$$\frac{(habitat\ x\ area\ in\ Y10 - habitat\ x\ area\ in\ Y0)}{habitat\ x\ area\ Y0} * 100$$

The results from the calculations for each habitat type, model and ST/SL scenario were placed into habitat delta (e.g., change) states according to the amount of habitat lost or gained. Bins for the states were: high loss was less than -50%; moderate loss was from -50% to -5%; static was from -5% to 5%; moderate gain was from 5% to 50%; and high gain was greater than 50% (Table 5). Data were calculated for all model scenarios and the four ST/SL scenarios in the BBN. Resulting habitat delta data for each habitat state, model and ST/SL scenarios were entered as a deterministic function dependent on the states of the parent nodes. When compiling a BBN in Netica, the states of a deterministic (versus chance) node are known with certainty as function of the parent node if the parent node states are all known.

Water Depth

The proportion of area of discrete water depths in marine and estuarine water habitats in Y10 was calculated based on the areas provided from each model scenario and ST/SL scenario. Data were provided as shapefiles by Mickey et al. (2020). States were established on a 2-meter scale from 0-meters sea level to 12-meters below sea level (bsl) (Table 5). ArcMap (version 10.6; Redmond, California) was used to process the raster data for calculation of the total area of each state in the model domain for each model and ST/SL. Frequency distributions for each state were calculated as the area of depth *x*, divided by the total area, multiplied by 100, or

$$\frac{area\ depth\ x}{total\ area} * 100$$

The results from these calculations were entered as probability distributions for each depth state (bin) totaling to 100 percent for each model and ST/SL scenario combination.

Water Depth Delta

Similar to habitat delta, we calculated water depth delta as the percent change in area for each water depth state under each model and ST/SL scenario from Y0 to Y10. These values were calculated as the area at the various water depth states in Y10 minus the area at the same water depth state in Y0, divided by the total water depth area in Y0, multiplied by 100, or

$$\frac{(\text{area at depth x in } Y10 \ - \ \text{area at depth x in } Y0)}{total\ area\ depth\ at\ x\ in\ Y0} * 100$$

The results from the calculations for each water depth delta, model and ST/SL scenario were placed into states according to area lost or gained. Bins for the states were: high loss was less than -15%; moderate loss was from -15% to -1%; static was from -0.9% to 0.9%; moderate gain was from 1% to 15%; and high gain was greater than 15% (Table 5). Data were calculated for all model scenarios and the four ST/SL scenarios in the BBN. Resulting water delta data for each water depth state, model and ST/SL scenarios were entered as a deterministic function dependent on the states of the parent nodes.

HSI Oyster

Oyster habitat suitability index (HSI) models were developed to “link the geophysical features of the barrier island and the water quality with habitat suitability for a critical species, *Crassostrea virginica* (eastern oyster)” (Enwright et al. 2020). Water quality parameters, including salinity, temperature, total suspended solids, dissolved oxygen and depth, were included in the model development. The relations between the HSI score and physical parameters were based on existing models with variable weights modified with local data. Details on how the models were developed and the results of the models are reported in Enwright et al (2020). Calculated HSI scores (0-1) were placed into one of four states, with scores >0.7 categorized as highly suitable, 0.5-0.7 as suitable, 0.3-0.5 as marginally suitable, and <0.3 as unsuitable. Areal coverage (ha) of each oyster suitability state was provided for the model domain for each model and ST/SL scenario. Frequency distributions for each suitability state (x) were calculated as the area of suitability state *x*, divided by the total area, multiplied by 100, or

$$\frac{area\ suitability\ state\ x}{total\ area} * 100$$

Values were provided by Enwright et al. (2020; Table B3, Page 71 and Table B4, Page 72) for each model and ST/SL scenario. The results from these calculations were entered as a probability distribution for each HSI state totaling to 100 percent for each model and ST/SL scenario combination.

HSI Seagrass

Similar to oyster HSI, seagrass HSI models link "the biological and ecological characteristics (percent coverage, aboveground biomass, and height) of [seagrass] species to environmental factors" Enwright et al. (2020). The dominant species found in the region was *Halodule wrightii* (shoal grass) and was chosen as the focal species on which to base the seagrass HSI models. Data on the effects of water quality, geomorphological variables, and hydrodynamic variables on *H. wrightii* were considered in building the seagrass HSI models. Details on how the models were developed and results of the models can be found in Enwright et al. (2020). Calculated HSI scores (0-1) were placed into one of four suitability states which were the same as those reported for oysters above. Frequency distributions for each suitability state (x) were calculated as the area of suitability state *x*, divided by the total area, multiplied by 100, or

$$\frac{area\ suitability\ state\ x}{total\ area} * 100$$

Values were provided by Enwright et al. (2020; Table C3, Page 92 and Table C4, Page 93) for each model and ST/SL scenario. The results from these calculations were entered as a probability distribution for each HSI state totaling to 100 percent for each model and ST/SL scenario combination to satisfy the CPT requirements in the BBN software.

Ecosystem Services List

The ecosystem services list node was compiled during an expert elicitation. Nineteen ecosystem services were identified by experts by brainstorming activities and collaborative discussion (Appendix A; Table 3A). Experts identified ecosystem services that were known or assumed to be provided by habitats on Dauphin Island. Using polling techniques during elicitation, experts individually indicated which ecosystem service was provided by each habitat type on Dauphin Island. The tallied number from all experts for each ecosystem service for each habitat was calculated and the results were ranked. The five ecosystem services with the highest total scores were included in the BBN. They were fish habitat, storm buffering, biodiversity, sediment and nutrient retention and water quality enhancement. Scores were normalized and populated into the CPT for this node (Table 6). The ecosystem services states informed the ecosystem services (Ecosystem Services) node.

Ecosystem Services

The ecosystem services node includes a range of suitability states (unsuitable. marginal, suitable, and highly suitable) and their impact on selected ecosystem services provided by habitats on Dauphin Island (see ecosystem services list node; Table 6). The node integrates states of habitat composition, HSI seagrass, HSI oyster, and habitat delta for each ecosystem service; states for the node were calculated in a spreadsheet based on combinations of state values from the parent nodes (Tables 7 and 8). To determine the state, the importance of each habitat (including HSI seagrass and HSI oyster) to the provision of each ecosystem service was assigned a value from 0 to 6, where 0 was not important and 6 was most important, based on scores from an expert elicitation (Table 7). Each habitat delta state from the habitat delta node was given a score (0-4), with 0 representing high loss and 4 representing high gain (Table 8). The habitat composition and habitat delta scores were multiplied to give a total habitat score. Similarly, the suitability state from the HSI oyster and HSI seagrass node output was assigned a score (0-3) based on suitability output, with 0 representing unsuitable and 3 representing highly suitable. The HSI seagrass and HSI oyster states were each multiplied by their respective suitability score to give a total score for both HSI seagrass and HSI oysters. The products of scores from habitat composition and habitat delta and HSI seagrass and HSI oysters were added to give a total score for each possible ecosystem service, habitat delta, habitat composition, HSI seagrass and HSI oyster state combination. The scores were normalized by dividing the raw combined score by the maximum value of all potential combinations. The distribution was placed into bins of 25% to identify the values associated with unsuitable, marginal, suitable and highly suitable states (Table 6). States for all potential child node combinations were input as a deterministic function into the ecosystem services node.

Managed Lands Critical Habitat

Potential impacts to critical habitat for piping plover (*Charadrius melodus*; managed lands critical habitat) were calculated as the change in the area (ha) of managed lands falling under United States Fish and Wildlife Service (USFWS) designated critical habitat from Y0 to Y10 for model and ST/SL scenarios. Calculations were made using USFWS piping plover critical habitat shapefile data acquired from USFWS at https://ecos.fws.gov/ecp/report/table/critical-habitat.html. We considered habitat above the mean low water line using digital terrain model boundary output from Mickey et al. (2020) and calculated potential change in critical habitat under each model and ST/SL scenarios. ArcGIS Pro (version 2.4.3; ESRI 2020) was used to assess the areal changes in critical habitat. These values were calculated as the area of critical habitat in Y10 minus the area of critical habitat in Y0, divided by the habitat area in Y0, multiplied by 100, or

$$\frac{(acres\ of\ critical\ habitat\ in\ Y10 - acres\ of\ critical\ habitat\ in\ Y0)}{acres\ of\ critical\ habitat\ in\ Y0} * 100$$

States ranged from high-loss to high-gain (5 states) based on overall changes in critical habitat over the 10 year horizon and were entered in the BBN as a deterministic function (Table 6).

Maximize Sustainability Utility

The value of restoration measures to habitat and ecosystem services were quantified in the maximize sustainability utility node. This utility node included input from ecosystem services, HSI oyster, HSI seagrass and managed lands critical habitat nature nodes. A total maximum sustainability utility value of 100 was equally distributed among the incoming nature nodes (Table 6; maximum utility for each child node was 25). Inputs from the child nodes were assigned scores based on the rule set defined for their states, and values were added (Table 6). For example, if critical habitat had high-gains (25), HSI oyster and seagrass each were highly-suitable (25 x 2 = 50), and ecosystem services was highly-suitable (25), then the utility value was

100 (Table 6.). Utility scores ranged from 0 to 100 and were entered into the BBN as a deterministic function.

Species Nodes

We developed a list of species of concern using the State Wildlife Action Plan (ALSWAP 2015), the USFWS threatened and endangered species list, and the expert opinion of regional faunal experts. The list included 48 species including birds, reptiles, amphibians, marine mammals, crayfishes and Gulf Sturgeon (Appendix A). We conducted a series of face-to-face and online consultations with the regional faunal experts to elicit specific habitat affinities for each species (Appendix A). Habitat affinity data were compiled specific to life history needs of fauna (e.g., foraging or nesting habitat) and were amended with rigorous literature review for each species. We also searched for data relative to population response to change in habitat due to ST/SL impacts. Experts assigned habitat values on elicitation spreadsheets for individual species by using a Likert scale of 0-5; where 0 was the least important habitat type and 5 was the most important for each species. Additional literature was searched to refine the habitat affinities (Appendix B).

Because the power of BBNs is maximized by carefully minimizing the complexity of the network, we selected species from the final list to represent species with similar habitat requirements based on a non-metric multi-dimensional scaling (NMDS) model created in R using the package ‘vegan’ (Oksanen et al. 2019). To conduct the analysis, the expert-derived habitat-species affinity database (Appendix A) was input to the NMDS model. The NMDS model oriented each species based on total differences in habitat affinity with the objective of scaling the orientation to best fit each difference and reduce the total ordination stress in the model (Figure 8). Total ordination stress measures how well the data fit in ordination space; the total stress in the NMDS for a two dimensional array was 0.15, indicating that the data fit moderately well. Our objective for the analysis was not to precisely fit the data, but rather to compile a general assessment about groups of species and their habitats. Based on the NMDS results and the available literature for each species on Dauphin Island, representative species were selected for each cluster of species with similar habitat use patterns (Table 9). Additional consideration for selection of surrogate species included species status (i.e., State or Federal species of concern), and the amount of information that was available for each species in the literature.

A total of 11 species was selected to represent the fauna on Dauphin Island based on the described NMDS: seaside sparrow (*Ammodramus caudacutus*), reddish egret (*Egretta rufescens*), American oystercatcher (*Haematopus palliates*), least tern (*Sternula antillarum*), Swainson's warbler (*Limnothlypis swainsonii*), loggerhead shrike (*Lanius ludovicianus*), brown pelican (*Pelecanus occidentalis*), piping plover, loggerhead sea turtle (*Caretta caretta*) , common bottlenose dolphin (*Tursiops truncates*), and Gulf sturgeon (*Asipenser oxyrinchus desotoi*; see Table 10 for a summary of surrogate species/habitat affinities and importance values). Because specific data for Dauphin Island (or even the region) for many of these species were not available, hypothesized relations between population response to losses and gains in habitat types predicted in the models were developed (Table 11). Population responses were dependent on the estimated value for each habitat type (0-5, where 0 was least and 5 was most valuable to the species; Table 10) and the loss/gain state (Table 11). Based on this rule set, associated probabilities of population response were added to the CPT. The predicted population responses from the BBN could be considered prior probabilities that can be updated during monitoring and adaptive management activities post restoration (see MAM plan; Steyer et al. 2020, USACE et al. 2020, Appendix K).

Maximize Coastal Resources Utility

The value of restoration measures on island fauna was quantified in the maximize coastal resources utility node. This utility node included input from surrogate species that used terrestrial and coastal habitats. The total utility score for coastal resources summed to 100 (Table 12). Utility scores for species were based on current IUCN (2020) listing and populations trends, with higher values given to threatened and endangered species or species with declining population trends (Table 12). Inputs from the child nodes were assigned scores based on the rule set defined for their states, and values were added (Table 6). For example, if seaside sparrow, brown pelican and oyster catcher each had increasing populations (8 x 3 = 24), least tern and Swainson's warbler each had increasing populations (12 x 2 = 24), piping plover and reddish egret each had increasing populations (16 x 2 = 32), and loggerhead shrike had increasing populations (20) then the utility value was 100 (Table 12). Utility scores ranged from 0 to 100 and were entered into the BBN as a deterministic function.

Maximize Marine Resources Utility

The value of restoration measures to species with habitat affinities for marine and estuarine water were quantified in the maximize marine resources utility node (Table 13). This utility node included input from surrogate species that had affinities for marine and estuarine habitats. The node also incorporated the values from the HSI oyster and HSI seagrass nodes. The total maximum utility score for maximize marine resources summed to 100 (Table 13). Utility scores for surrogate species were based on current International Union for Conservation of

Nature (IUCN 2020) listing and population trends. Higher scores were assigned to threatened and endangered species (Gulf sturgeon; utility score was 20). The highest scores were assigned to HSI oyster and HSI seagrass (25) because each represents marine ecosystems and provides additional benefits (Table 13). Inputs from the child nature nodes were assigned scores based on the rule set defined for their states, and values were added (Table 6). For example, if loggerhead sea turtle and bottlenose dolphin had increasing populations (15 x 2), Gulf sturgeon had increasing populations (20) and HSI oyster and HSI seagrass each were highly suitable (25 x 2 = 50), then the utility value was 100 (Table 13). Utility scores ranged from 0 to 100 and were entered into the BBN as a deterministic function.

Variables Related to Social Acceptance and Costs

There were a suite of variables included in the BBN that were identified as important to stakeholders. They informed the social acceptance (Maximize Social Acceptance) utility node and/or the Minimize Cost utility node.

Cultural Resources

Cultural resources were quantified as the presence or absence of National Registrar of Historic Sites within areas affected by each of the proposed models and ST/SL scenarios. The cultural resources considered were the Sand Island Lighthouse located offshore along the Mobile ebb tidal delta and Fort Gaines located on the eastern terminal end of Dauphin Island. Data were obtained from the National Historic Registry of Sites of the States Coastal Marine Planning Portal at https://www.gsa.state.al.us/apps/CMP/current/ and states were determined for all combinations of parent node states as containing the Lighthouse, the Fort, or Neither, and entered as a deterministic function.

Managed Lands Parks

Managed lands parks node quantified the number of local, county, state or federally managed lands or parks that benefited from restoration measures within the area for each model and ST/SL scenario. Management agencies or organizations responsible for public lands and parks included Dauphin Island Park and Beach Board, the Nature Conservancy, Mobile County, Alabama Department of Conservation and Natural Resources, Mobile Bay National Estuary Program and USFWS. Data were obtained from the Mobile County, Alabama, GIS Department (https://www.mobilecountyal.gov/government/gis-mapping) and we calculated the number of managed lands and parks impacted above the mean high water line using digital terrain model output from Mickey et al. (2020). The spatial analysis tool in ArcGIS Pro (version 2.4.3; Redmond, California) was used to assess the number of properties that benefited from restoration measures. The number of properties ranged from 0 to 4 and associated states indicated benefits of restoration measures on properties from no benefit (Benefit 0) to high benefit (Benefit 4; Table 14). States were determined simply by the number of properties.

Percent Reduction Overwash

Percent reduction overwash was defined as the estimated percent reduction in overtopping occurrence derived from the XBeach model output (Mickey et al. 2020) by calculating the total number of hours that water levels were greater than the maximum island elevation at vulnerable areas susceptible to overwash (the West End of Dauphin Island and all of Pelican Island). This was conducted by comparing the no-action model results to results for other model and ST/SL scenarios (Mickey et al. 2020; summary on Pages 37-42). The results were placed into states of low (highest incidence of overtopping), medium, or high (lowest incidence of overtopping) based on the hours of occurrence and the area of the island that overtopping was reduced (Table 14). States were entered into the BBN as a deterministic function of the parent nodes.

Percent Reduction Breaching

Percent reduction breaching was the estimated percentage of reduced breaching events from each model and ST/SL scenario throughout the 10-year simulation period compared to the no-action cases from Mickey et al. (2020). The values of the states were estimated at 0 percent, 40 percent and 100 percent. The calculated values were placed into states based on their respective percent reduction (0 percent, 40 percent, or 100 percent). States were entered into the BBN as a deterministic function of the parent nodes (Table 14).

Managed Lands Coastal Barrier Resources Act (CBRA) Zone

Managed lands CBRA zone quantifies the percent change in acreage designated USFWS Coastal Barrier Resources Act zoned lands for each model and ST/SL scenario from Y0 to Y10. Calculations were made using USFWS CBRA boundary shapefile data obtained at https://www.fws.gov/cbra/maps/Boundaries.html. We considered habitat above the mean low water line using digital terrain model boundary output from Mickey et al. (2020) and calculated potential change in critical habitat under each model and ST/SL scenario. The spatial analysis tool in ArcGIS Pro (version 2.4.3; Redmond, California) was used to assess the areal changes in critical habitat. These values were calculated as the acreage in the CBRA zones in Y10 minus the acreage of CBRA zoned lands in Y0, divided by the acreage of CBRA zone lands in Y0 and multiplied by 100, or

$$\frac{(area\ of\ CBRA\ zone\ lands\ in\ Y10 - area\ of\ CBRA\ zone\ lands\ in\ Y0)}{area\ of\ CBRA\ zone\ lands\ in\ Y0} * 100$$

States ranged from high-loss to high-gain (5 states) based on overall changes in CBRA zoned lands over the 10 year horizon and were entered in the BBN as a deterministic function (Table 14).

Impacted Private Properties

We calculated area of private property based on Mobile County parcel shapefile data that were provided by Mobile County, Alabama GIS division (https://www.mobilecountyal.gov/government/gis-mapping) above the mean high water line using digital terrain model output from Mickey et al. (2020) indicating the potential change in private land for each model and ST/SL scenario. Impacted private properties is the percent change in acreage of private properties under each alternative and model scenario from Y0 to Y10. These values were calculated as the area of private property in Y10 minus the initial area of private property in Y0, divided by the initial acreage of private properties at Y0 and multiplied by 100, or

$$\frac{(area\ of\ private\ property\ in\ Y10 - area\ of\ private\ property\ inY0)}{area\ of\ private\ property\ in\ Y0} * 100$$

States ranged from high-loss to high-gain (5 states) based on overall changes in CBRA zoned lands over the 10 year horizon and were entered in the BBN as a deterministic function (Table 14).

Impacted Public Properties

This node quantified the change in acreage of public properties for each model and ST/SL scenario from Y0 to Y10. Area of public property was calculated based on Mobile County parcel shapefile data that were provided by Mobile County, Alabama GIS Division (https://www.mobilecountyal.gov/government/gis-mapping) above the mean high water line using digital terrain model output from Mickey et al. (2020). The spatial analysis tool in ArcGIS Pro (version 2.4.3; Redmond, California) was used to assess the areal changes in public properties to assess changes in these lands for each model and ST/SL scenario. Values were calculated as the area of public property in Y10 minus the initial area of public property in Y0, divided by the initial acreage of public properties at Y0 and multiplied by 100, or

$$\frac{(area\ of\ public\ property\ in\ Y10 - area\ of\ public\ property\ in\ Y0)}{area\ of\ public\ property\ in\ Y0} * 100$$

States ranged from high-loss to high-gain (5 states) based on overall changes in public property over the 10 year horizon and were entered in the BBN as a deterministic function (Table 14).

Maximize Service Time

Maximizing the service time (minimizing the time to reach maximum benefits and maximize the total time of realizing benefits at minimized costs) was an important consideration to stakeholders. The maximize service time node was parameterized for each restoration model and ST/SL scenario by determining how long (in years) it would take to incur positive restoration benefits (from immediate to within 5 years) and the amount of additional maintenance required to maximize benefits (from minimal to significant; Table 14). The data to parameterize the node were generated by USACE expert opinion and were informed in the BBN in states of low, medium, or high (Table 14). Note maximize service time was parameterized such that “high” values contributed less to the overall utility of the node outcome. The states were entered as a deterministic function of the parent node states.

Maximize Social Acceptance Utility

The maximize social acceptance utility node estimates the value of social factors related to implementing restoration measures. This utility node was the combined states of cultural resources, managed lands parks, percent reduction overwash, percent reduction breaching, managed lands critical habitats, managed lands CBRA zone, impacted private properties, impacted public properties, and maximum service time. The maximize social acceptance utility value was derived using rules defining utility scores associated with states of parent nodes (Table 14). Higher maximum utility scores were associated with cultural resources (15) and impacted private and public properties (15); all other parent nodes had a maximum utility score of 10; values were added and the total maximum utility was 100 (Table 14). For example, if the utility score of cultural resources was 15, managed lands parks was 10, percent reduction overwash was 10, percent reduction breaching was 10, managed lands critical habitat and managed lands CBRA each were 10 (10 x 2 = 20), impacted private and public lands each were 15 (15 x 2 = 30) and maximize service time was 10, then the total utility score would be 100. Combined utility scores ranged from 0 to 100 and were entered into the BBN as a deterministic function (Table 14).

Cost Estimation

The cost nature nodes were parameterized by USACE; they used procedures for estimating cost associated with restoration measures. The methodology used was the USACE Civil Works Cost and Engineering Regulations. The specifics are outlined in Appendix K of the final report for ALBIRA (USACE et al. 2020).

Initial Cost

Initial cost represented the estimated cost to implement the proposed measure with the given option for acquiring materials (USACE et al. 2020). Initial Costs included design and management costs as well as a 10% contingency. Initial costs ranged from $0 (Measure 1 – Status Quo) to $216,081,000 (Measure 4 -West End and Katrina Cut Beach and Dune Nourishment with Buyout – Option 1). Costs were placed into categories based upon the value and limits within the proposed budget (Table 15).

Maintenance Cost

Maintenance cost represents the estimated cost to maintain the proposed measure with the given option of acquiring materials over a period of 20 years (USACE et al. 2020). This temporal model horizon (20 years) differs from the horizon for the other variables (10 years) in the BBN based on input by the stakeholders to account for a feasible time frame associated with restoration maintenance actions. Maintenance costs ranged from $0 (Measure 1 – Status Quo, Measure 9 – Back Barrier Tidal Flats and Marsh Habitat Restoration, Measure 10 – Back Barrier Tidal Flats and Marsh Habitat Restoration – Marsh Habitat Restoration behind Katrina Cut, Measure 12 – Aloe Bay Marsh Restoration, Measure 17 – Katrina Cut Sand Berm Nourishment – Removal of Katrina Cut Rubble Mound Structure, and Measure 18 – West End Backbarrier Herbaceous Dune Plant Restoration) to $158,432,000 (Measure 4 -West End and Katrina Cut Beach and Dune Nourishment with Buyout – Option 2). Costs were placed into states based upon the value and limits within the proposed budget (Table 15).

Public Access

This node quantified whether public access (such as public parking areas, access points and facilities) was impacted (yes/no) for each model and ST/SL scenario. Areas of public access were identified based on Mobile County parcel shapefile data that were provided by Mobile County, Alabama GIS division (https://www.mobilecountyal.gov/government/gis-mapping) above the mean high water line using digital terrain model output from Mickey et al. (2020). The spatial analysis tool in ArcGIS Pro (version 2.4.3; Redmond, California) was used to assess changes to whether the public could access sites for each model and ST/SL scenario.

Public Infrastructure Benefit

Public infrastructure benefit (yes/no) indicated whether public infrastructure such as buildings, roads, and utilities would benefit from reduced land damages due to proposed restoration measures. Assessments of reduced land damages were conducted by evaluating the potential loss of land through erosion or reduced debris removal during overtopping events using the digital terrain model output from Mickey et al. (2020) indicating the potential change in land under each model and ST/SL scenario. The spatial analysis tool in ArcGIS Pro (version 2.4.3; Redmond, California) was used to assess benefits (yes/no) for each model and ST/SL scenario (Table 14).

Minimize Cost Utility

The minimize cost utility node is the value of implementing the restoration measure, operate and maintain the measure, as well as additional costs associated with public access, impacted private properties, cultural resources, public infrastructure and. A maximum total cost utility score of 100 was possible from the combination of the parent node states, with slightly higher utility values placed on the low-acceptable initial cost and low maintenance cost; the other linked nodes had maximum values of 15 (Table 15). For example, if initial and maintenance costs each were low (20 x 2 = 40) and public access, public infrastructure benefit, cultural resources, and impacted private properties each were valued at 15 (15 x 4 = 60) then the total utility would be 100 (Table 15). Combined utility scores ranged from 0 to 100 and were entered into the BBN as a deterministic function (Table 15).

Land Conservation BBN Utility Nodes

Land Conservation Utility

Multiple properties have been identified for purchase (USGS et al. 2017) and were included as individual decisions in the land acquisition BBN. Their utility was evaluated through combining multiple attributes associated with each parcel. We considered the development risk, the scarcity of the habitat on the parcel, the overall size in acres, and whether the parcel was adjacent to land already in conservation status. We combined the individual scores from the attributes to provide an overall conservation utility score, and then normalized the data such that the highest value was 100 (Table 16).

Purchase Land Utility

The cost associated with acquiring lands for conservation purposes was given utility scores for ranks based on the estimated cost of acquisition. Land acquisition costs ranged from $200,000 to $2,500,000. Each land acquisition proposed was placed into a state based on the estimated cost of acquisition (Table 17). Each state was assigned a utility score from 0 to 100, prioritizing lower-cost options by ranging scores from 100 for the lowest cost options to a score of 0 for the highest cost options (Table 17). Utility values were entered into the BBN as a deterministic function.

Decision Optimization

The optimal decisions were determined by examining the expected value associated with each alternative decision, which was the sum of the probability-weighted utility values.

$$U_{total} = \sum_{j=1}^{n} \sum_{i=1}^{n_j} p_{ij} u_{ij}$$

where,

n is the number of states for node *j*,

p is the probability of state *i* for node *j*, and

u is the value of state *i* for node *j*.

The modeled decision with the highest expected value was considered the optimal decision.

Sensitivity analysis

One-way sensitivity and response profile analysis were conducted to assess uncertainty regarding the influence of state variables on the optimal decisions. One-way sensitivity analysis considers the range of probabilities for individual state variables and their influence on the utility of the measures (potential restoration decisions). A tornado diagram was constructed to visualize the relative influence of the state variables on the decision. Response profiles were compiled for the different responses of several state variables to assess their influence on the utility of the various measures. Similar to one-way sensitivity analysis, one model component was varied to evaluate the impact on the expected value for each decision. We conducted this for three species, HSI seagrass and HSI oyster and ecosystem services components to determine if the decision changed relative to predicted responses in the model components. We followed methods outlined in Conroy and Peterson (2013).

Results

The development of the influence diagram, decision framework, BBN and the subsequent parameterization of the BBN constituted the bulk of this work and is described in detail in the methods section.

Decision optimization

When all the states in the decision support model were informed (Figures 3 and 4), the network was compiled to calculate the additive utility value for each decision separately, either as a restoration measure or as a land purchase (Table 18). Of the proposed structural measures, the East End Beach and Dune Restoration (all three options) had the highest utility (301.094), for many other restoration measures utility values were nearly equal; the range of values for the next 10 ranked measures ranged only from 221.878 to 231.122. The Dauphin Island 39 parcel property acquisition: parcel B – Graveline Bay ranked the highest (142.200) of the non-structural measures (Table 18). Utility values were more variable for the land acquisition decisions ranging from 142.000 to 8.700).

Sensitivity Analysis

The results of the sensitivity analysis indicated that many variables influenced the optimal decision (Figure 9). However, the most influential variables on the decision were ecosystem services, bottlenose dolphin, HSI seagrass, and HSI oyster. Other individual surrogate species were also influential. The least influential variable was managed lands parks.

Response profiles for the ecosystem services, bottlenose dolphin, HSI seagrass and HSI oyster, Swainson's warbler and loggerhead sea turtle nodes demonstrated that the structural measure of East End Beach and Dune Restoration (i.e., M8 Op 1, 2, and 3; see Table 1 for description of the measure) was identified as the optimal measure and was consistent for all states of each node (Figures 10-15). The expected utility of the decisions changed among states of the nodes and increased as node states were more suitable or population response increased. The ranks of the decisions were the same for each state variable for which we constructed response profiles with the exception of ecosystem services. For the ecosystem services node, the Pelican Island Sand Nourishment (M3) ranked 4th (instead of 6th) for the ecosystem services node. The ranks for decisions from the response profiles were also slightly different than the ranks from the fully complied BBN; the top ranked decisions were similar but were not in the same order and had expected utility values that varied only by 10 units.

Discussion

Restoration decisions involve complex social, economic, and ecological aspects coupled with technical application and design, each of which have multiple levels of uncertainty including uncontrollable future conditions (Guerrero et al. 2017). These characteristics inherently influence the predictability of outcomes associated with decisions as well as the difficulty in evaluating tradeoffs among restoration measures. In the case of ALBIRA, integrated technical modeling efforts quantified multiple areas of uncertainty associated with restoration design and the costs of restoration measures and the decision analysis allowed for a process for evaluating the consequences of implementing each measure on multiple stakeholder objectives by incorporating those technical data into the BBN. In addition, the decision analysis may be used in evaluation of selected restoration measures where probability distributions associated with each model can be updated by monitoring the physical performance of implemented restoration measures and the associated outcomes of measured state variables (e.g., habitat, water quality, and/or faunal population response).

Coastal restoration fits into a class of problems considered “wicked” in that solutions are often ill defined and do not encompass system complexity; problem solving will require adaptation and learning-based risk assessment (Moser et al. 2012). Adaptive management for decision-making related to coastal restoration has been suggested as a process for evaluating restoration actions with an emphasis on learning and reduction of uncertainty (Walters 1997; Hackney 2000; Moser et al. 2012). Structured decision-making (a non-iterative process) can provide the set-up phase for iterative adaptive management (AM; Williams et al. 2007), especially when predictive models, such as those developed in ALBIRA and integrated into the BBN, are available (Moser et al. 2012). Both SDM and AM processes are stakeholder driven and constitute transparent analyses of how potential decisions influence multiple objectives (Williams et al. 2007). Moreover, many assessments of restoration actions do not consider socioeconomic values associated with potential decisions (Aronson et al. 2010). In the case of ALBIRA, minimizing social impacts (e.g., maximizing social acceptance) and minimizing costs were explicitly included in the BBN. Although some of the causal relations in the BBN were simplified (e.g., impacted public infrastructure; yes or no), the underlying technical models can be queried to provide more information about the responses to the state variables in the BBN.

The restoration measures that had the highest utility in the BBN were those that best satisfied the complex multiple stakeholder objectives associated with social, fiscal and conservation values on Dauphin Island. The highest ranked restoration measure was one that minimized impacts to freshwater wetlands, open freshwater and woody habitats (e.g., maritime forest) on the east end of Dauphin Island, especially in the highest sea level rise and storminess scenarios. The measure also had low initial and maintenance costs as well as provision of multiple benefits to society (e.g., low impact on infrastructure, gains in critical habitat and CBRA zoned lands). In terms of the marine natural resources, coastal natural resources and sustainability utilities, this measure increased the probability that the population response for most species would be positive. For many species that inhabit Dauphin Island, data are lacking regarding population response to past restoration actions or environmental variation. The monitoring and adaptive management plan that was prepared for ALBIRA (Steyer et al. 2020) sets forth the elements to implement iterative learning on Dauphin Island relative to responses of objectives to restoration.

Restoration ecology planning often does not include ecosystem services, attributes provided by ecosystems that benefit humans and may be associated with proposed restoration actions (Martin et al. 2018). During ALBIRA, occupational experts provided knowledge regarding species' habitat affinities and ecosystem services provided by habitats and by oysters and seagrasses. Their knowledge was corroborated by a review on coastal ecosystem services (Barbier et al. 2011) and primary literature for the species (Appendix B). The one-way sensitivity analysis indicated that the expected value of the optimal decision was influenced by many state variables in the BBN but it was most influenced by marine and coastal natural resources and ecosystem services. Inclusion of ecosystem services and goods is important to assess the value of restoration measures toward sustainable futures (Sidle et al. 2013). However, in this study we did not place economic value on either the ecosystem services provided by restored Dauphin Island habitats, or the potential economic benefits provided by lands available for purchase. For example, purchase of submerged lands adjacent to Dauphin Island could economically benefit nearshore fisheries, such as brown and pink shrimp, and crabs (Barbier et al. 2011; Lai et al. 2020).

Selection of restoration measures could also involve portfolios of measures and their impacts on meeting the objectives of stakeholders. In this case, the decision network evaluates one measure against another, and although tradeoffs can be evaluated, the outcomes associated with implementation of multiple measures are not necessarily additive. More value might be realized from synergistic relations among restoration measures, some of which come from landscape ecology principles of patch size, juxtaposition, and connectivity of habitat types (Leite et al. 2013). In addition, fine scale habitat characters (e.g., stem density, grain size, slope) were not evaluated in this study yet they could be measured in monitoring and used in the future to differentiate among restoration actions (e.g., Torres et al. 2008).

The use of structured decision-making techniques offers many advantages for choosing among restoration measures especially when complex data can be integrated to assess trade-offs for meeting complex, competing objectives (Gregory and Keeney 2002). In addition the process helps eliminate common hurdles for decision makers including psychological pitfalls that impede smart decision-making. These include sunk costs (using past decisions to justify future decisions even if the previous decisions may not have been sound), anchoring (starting with numerical values derived from limited knowledge, but ultimately influence the decision), and availability bias (where humans tend to overestimate the probability of highly visible events (Schwenk 1988;

Gregory and Keeney 2002)). Each of these biases could impact decisions, if decision-making processes are not informed by the best available science to assist in evaluation of consequences of future restoration actions (Kunreuther et al. 2009).

Finally, the evaluation of biological, social, economic and landscape change affected by restoration actions under uncertain environmental futures during this study provided an assessment of a highly dynamic coastal ecosystem and a robust tool for decision makers. Interactive trade-off analysis by decision makers and stakeholders using the BBN software could allow for more transparency for, and understanding of, the complexities of evaluating the restoration measures (Marcot et al. 2006). In addition, the BBN is flexible and could be modified if variables germane to decision-making are not included in this version of the network. The technical models that were constructed during ALBIRA and used to inform the BBN are available for new queries if warranted.

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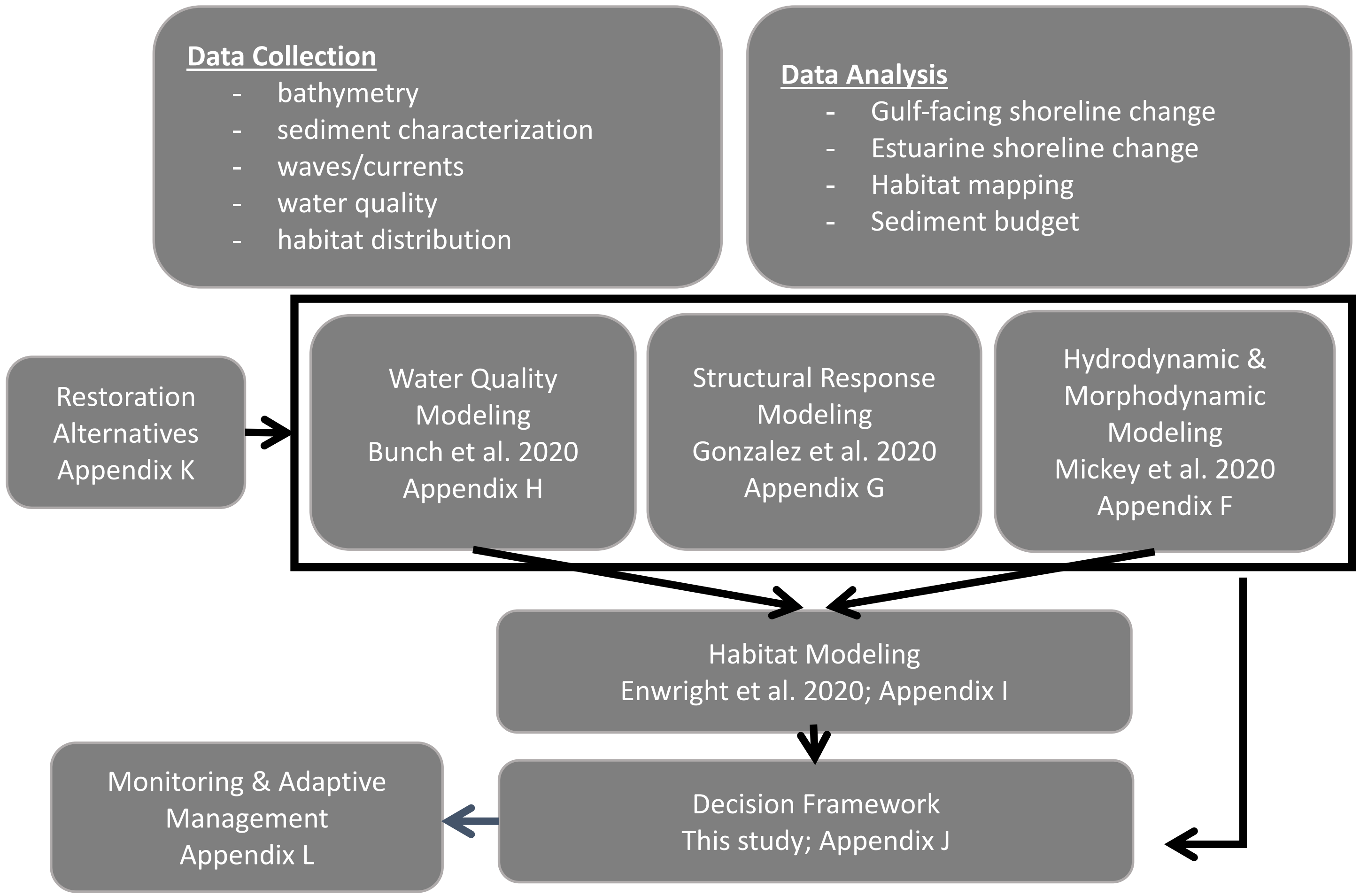

Figure 1. Flow chart indicating the various data sets that were used to inform the structured decision-making framework to predict the consequences of various restoration measures on Dauphin Island. See https://gom.usgs.gov/DauphinIsland/Reports.aspx for reports and publications associated with the studies (Appendices F-L) conducted under Alabama Barrier Island Restoration Assessment (ALBIRA). Note that Bunch et al. (2020) was used in the habitat modeling but was not explicitly used to inform the Bayesian Belief Network for ALBIRA.

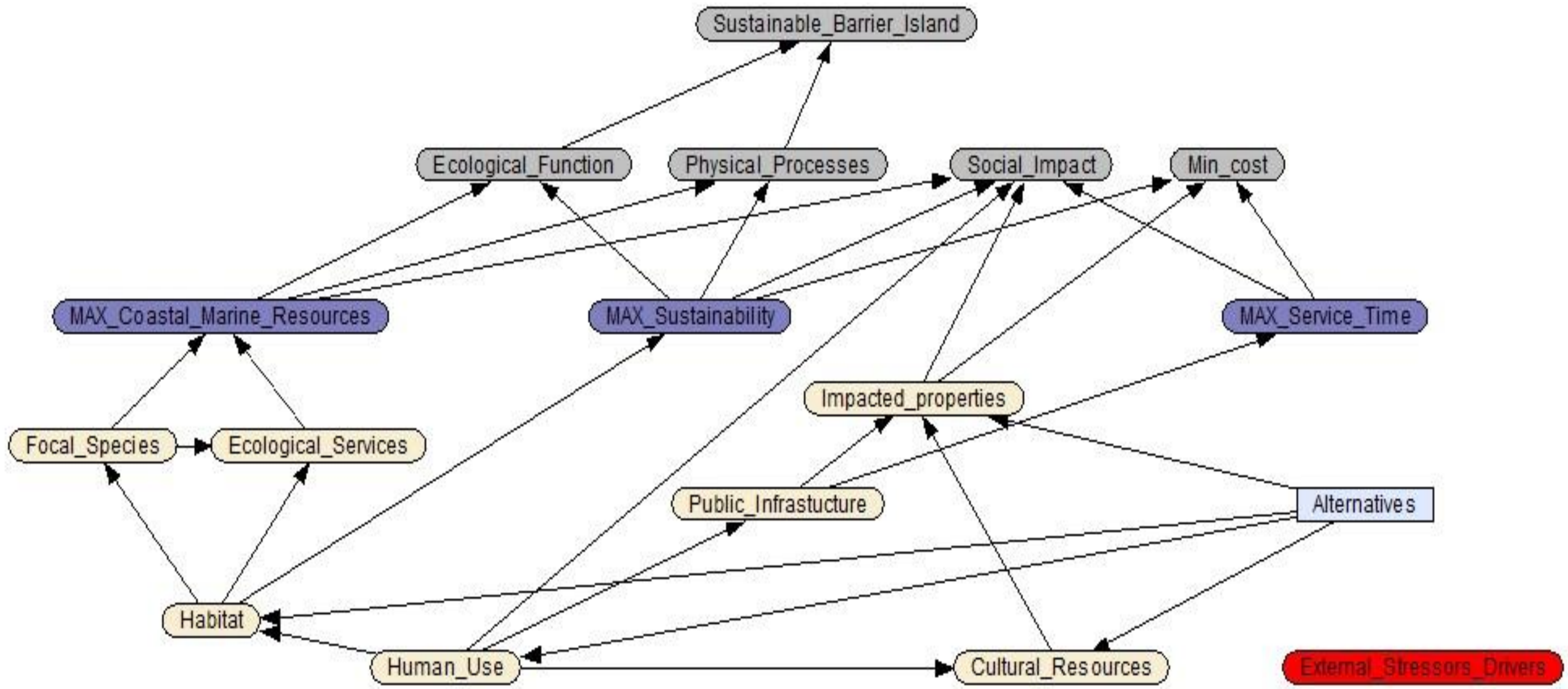

Figure 2. Draft influence diagram showing causal links among objectives and decision elements. Because this was a draft, some of the nodes became state nodes and some of them were utility nodes in the final Bayesian Belief Network (BBN). In this draft, yellow nodes were objectives that could be quantified. In the final BBN, the purple nodes were higher level objectives that became utility nodes, with the exception of Max_Service_Time that became a nature node (see text for description). Gray nodes were also higher level objectives in the initial influence diagram; the red node represented storms and sea level rise, and the blue node represented decision alternatives. This diagram was initially published in the Interim Report (USGS et al. 2017).

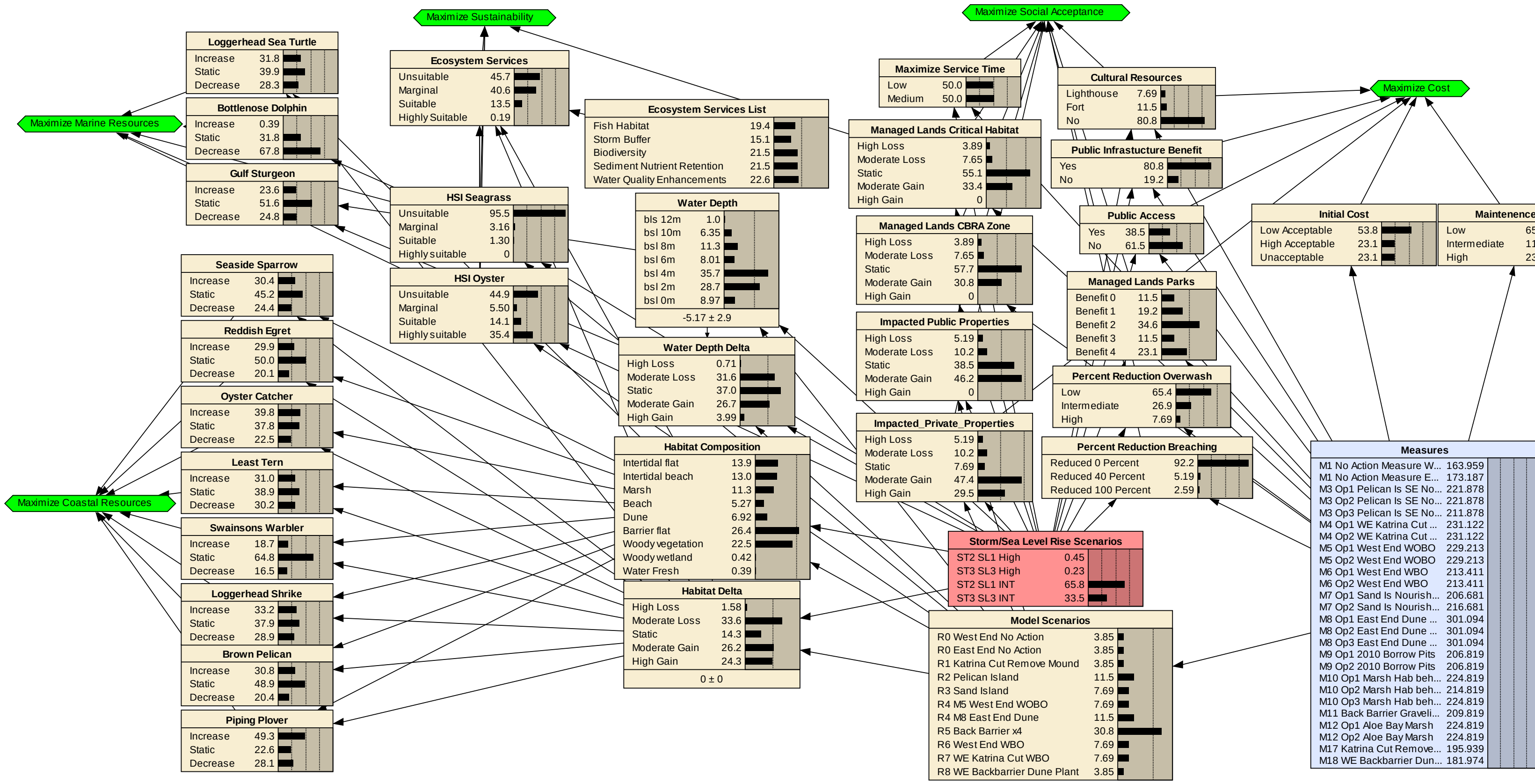

Figure 3. Bayesian belief network showing decision node (blue rectangle), nature nodes (yellow rectangles; state variables) and equally-weighted utility nodes (green hexagons) associated with structural restoration measures on Dauphin Island, Alabama. The red node quantified the probabilities of various storm and sea level scenarios. Each state variable has a number of states (listed in nature nodes) and conditional probabilities associated with the likelihood of states were calculated by compiling the network in the software (Netica version 1.12, Norsys Software Corporation: Vancouver, British Columbia). The black bars in the nature nodes indicate state likelihoods. See text for descriptions of individual nodes. The black arrows are arcs that represent causal relations among nodes. The final expected value (utility scores) associated with each restoration measures (i.e., decision utilities) are reported in the decision node and in Table 18.

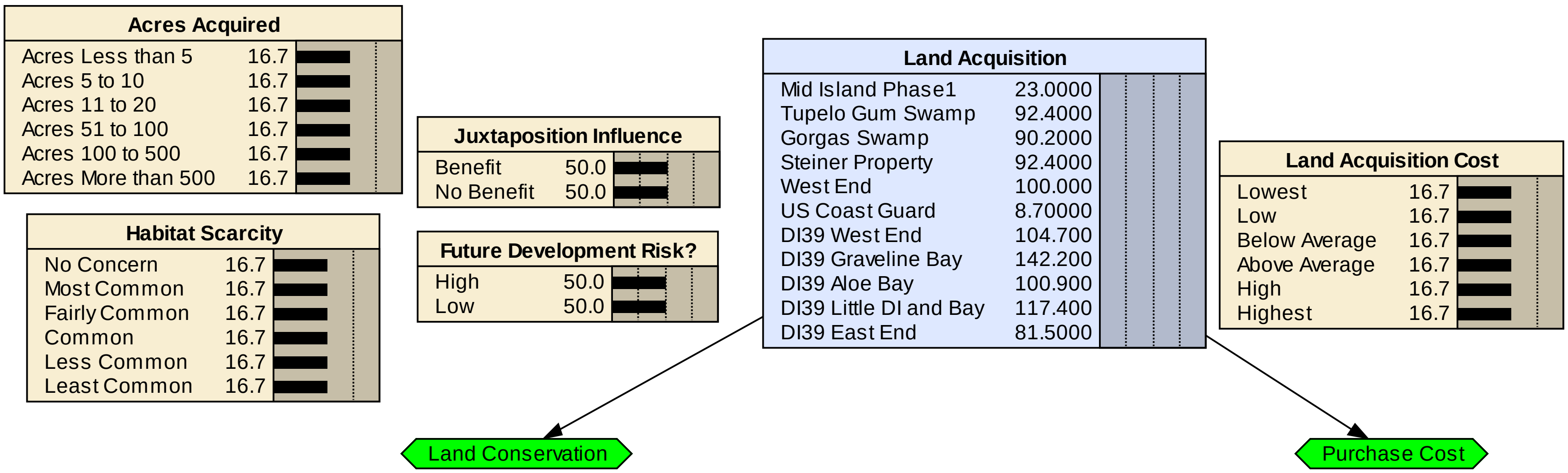

Figure 4. Bayesian belief network (BBN) showing decision node (blue rectangle), nature nodes (yellow rectangles; state variables) and equally-weighted utility nodes (green hexagons) associated with land acquisition parcels on Dauphin Island, Alabama. Black arrows (arcs) indicated the causal relations in the BBN. The utility for land conservation value was a combined score of acres acquired (total acreage of parcel), habitat scarcity (how common was the habitat type on the island), juxtaposition influence (was the parcel adjacent to conservation land?), and future development risk (could the property be developed?). The purchase cost utility was a deterministic function of purchase price (USGS and USACE 2017). Uniform likelihoods (black bars in nature nodes) are depicted in the figure; see Table 16 and 17 for state values that informed the utility nodes. When the BBN was compiled using the software (Netica version 1.12, Norsys Software Corporation: Vancouver, British Columbia) The final expected value (utility scores) associated with each land parcel (i.e., decision utilities) were calculated. They are reported in the decision node and in Table 18.

Netica - [Habitat_Composition Table (in Bayes net influence_draft6_to_DMv3)]

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Storm_SLR_Scenarios	Model_Scenarios	Intertidal flat	Intertidal beach	Marsh	Beach	Dune	Barrier flat	Woody vegetation	Woody wetland	Water Fresh
ST2 SL1 High	R0 West End No Action	7.407	9.909	7.938	3.619	7.096	23.943	39.359	0.37	0.36
ST2 SL1 High	R0 East End No Action	10.196	3.94	7.693	5.122	8.705	30.307	32.834	0.643	0.559
ST2 SL1 High	R1 Katrina Cut Remove Mound	14.18	12.88	7.49	4.52	8.14	28.4	23.33	0.5	0.56
ST2 SL1 High	R2 Pelican Island	13.639	13.405	7.149	5.365	7.491	29.387	22.544	0.482	0.539
ST2 SL1 High	R3 Sand Island	14.12	13.13	7.43	4.54	8.13	28.31	23.28	0.5	0.56
ST2 SL1 High	R4 M5 West End WOBO	8.678	11.508	9.788	4.289	9.478	30.494	24.915	0.45	0.4
ST2 SL1 High	R4 M8 East End Dune	10.119	3.93	7.629	5.149	8.739	30.287	32.977	0.63	0.54
ST2 SL1 High	R5 Back Barrier x4	16.07	12.44	7.26	4.17	8.23	28.11	22.68	0.49	0.55
ST2 SL1 High	R6 West End WBO	13.76	12.27	7.65	4.63	8.53	29	23.15	0.49	0.52
ST2 SL1 High	R7 WE Katrina Cut WBO	13.261	10.731	7.301	4.4	9.061	32.193	22.092	0.47	0.49
ST2 SL1 High	R8 WE Backbarrier Dune Plant	14.18	12.88	7.49	4.52	8.14	28.4	23.33	0.5	0.56
ST3 SL3 High	R0 West End No Action	17.996	16.369	9.138	4.282	4.865	15.182	31.357	0.48	0.331
ST3 SL3 High	R0 East End No Action	10.082	5.789	10.13	6.138	8.555	32.645	25.963	0.39	0.308
ST3 SL3 High	R1 Katrina Cut Remove Mound	25.87	22.92	10.76	5.96	3.05	14.73	16.64	0.07	0
ST3 SL3 High	R2 Pelican Island	25.943	22.442	10.651	6.011	3.16	15.092	16.632	0.07	0
ST3 SL3 High	R3 Sand Island	25.687	23.058	10.679	5.829	3.26	14.859	16.548	0.08	0
ST3 SL3 High	R4 M5 West End WOBO	19.958	15.868	9.819	4.53	4.93	17.378	26.707	0.48	0.33
ST3 SL3 High	R4 M8 East End Dune	9.559	5.589	9.779	5.949	8.289	31.147	28.867	0.38	0.44
ST3 SL3 High	R5 Back Barrier x4	26.863	21.812	11.161	5.871	3.11	14.962	16.152	0.07	0
ST3 SL3 High	R6 West End WBO	25.845	21.276	11.648	6.019	3.039	16.257	15.837	0.08	0
ST3 SL3 High	R7 WE Katrina Cut WBO	25.393	20.602	11.201	5.721	3.18	19.142	14.691	0.07	0
ST3 SL3 High	R8 WE Backbarrier Dune Plant	25.87	22.92	10.76	5.96	3.05	14.73	16.64	0.07	0
ST2 SL1 INT	R0 West End No Action	8.093	12.145	10.657	4.475	8.695	29.429	25.611	0.454	0.442
ST2 SL1 INT	R0 East End No Action	8.861	3.944	9.073	5.13	8.721	30.354	32.706	0.651	0.56
ST2 SL1 INT	R1 Katrina Cut Remove Mound	11.109	12.869	10.509	4.55	8.129	28.467	23.288	0.52	0.56
ST2 SL1 INT	R2 Pelican Island	10.671	13.393	10.058	5.388	7.492	29.458	22.507	0.494	0.539
ST2 SL1 INT	R3 Sand Island	11.06	13.13	10.45	4.54	8.14	28.34	23.26	0.52	0.56
ST2 SL1 INT	R4 M5 West End WOBO	7.77	11.51	10.69	4.29	9.48	30.5	24.91	0.45	0.4
ST2 SL1 INT	R4 M8 East End Dune	8.798	3.929	8.948	5.149	8.738	30.304	32.953	0.64	0.54
ST2 SL1 INT	R5 Back Barrier x4	11.051	12.401	12.171	4.19	8.231	28.283	22.622	0.5	0.55
ST2 SL1 INT	R6 West End WBO	10.839	12.269	10.559	4.619	8.539	29.027	23.118	0.51	0.52
ST2 SL1 INT	R7 WE Katrina Cut WBO	10.361	10.729	10.175	4.389	9.133	32.154	22.08	0.482	0.496
ST2 SL1 INT	R8 WE Backbarrier Dune Plant	11.109	12.869	10.509	4.55	8.129	28.467	23.288	0.52	0.56
ST3 SL3 INT	R0 West End No Action	16.01	15.471	9.901	5.723	5.083	19.117	27.843	0.498	0.353
ST3 SL3 INT	R0 East End No Action	11.288	5.429	10.732	5.775	8.033	30.734	27.35	0.37	0.289
ST3 SL3 INT	R1 Katrina Cut Remove Mound	24.253	19.627	12.548	6.949	2.869	17.482	15.467	0.794	9.93e-3
ST3 SL3 INT	R2 Pelican Island	24.388	19.178	12.699	7.099	3.01	17.958	15.588	0.07	1.00e-2
ST3 SL3 INT	R3 Sand Island	24.418	19.898	12.479	6.829	3.09	17.718	15.478	0.08	1.00e-2
ST3 SL3 INT	R4 M5 West End WOBO	15.25	15.46	10.74	5.93	4.91	20.38	26.53	0.47	0.33
ST3 SL3 INT	R4 M8 East End Dune	11.029	5.419	10.689	5.759	8.029	30.297	27.977	0.37	0.43
ST3 SL3 INT	R5 Back Barrier x4	24.02	19.07	13.6	7.12	2.91	18.17	15.03	0.07	1.00e-2
ST3 SL3 INT	R6 West End WBO	23.515	19.146	12.817	6.879	2.879	19.806	14.877	0.08	0
ST3 SL3 INT	R7 WE Katrina Cut WBO	22.128	19.008	12.899	5.809	3.13	23.088	13.849	0.08	1.00e-2

Figure 5. Example of a conditional probability table that represents the probability of various habitat types (columns 3-11) occurring at the end of 10 years (data from Enwright et al. 2020, Tables A6-A9) subject to four sea level and storm scenarios (column 1) and nine restoration model scenarios (column 2; R1-R8; R4 includes two models, R4 M5 West End, R4 M8 East End, see our Table 1 and 3) and two no action options (R0 West End, R0 East End). Note that the full table is not depicted in this figure. .

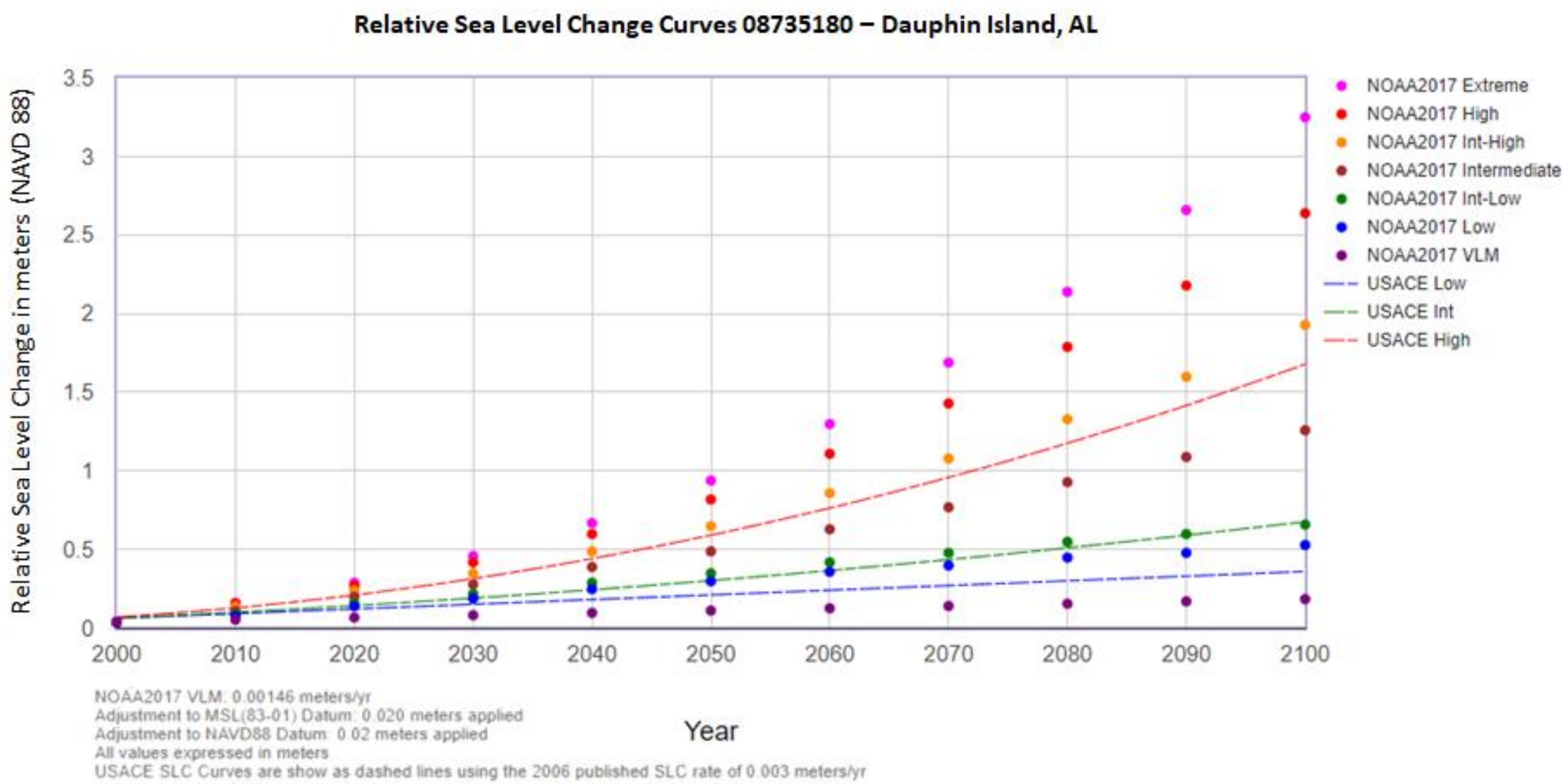

Figure 6. Relative sea level change curves for tide gage 8735180 at Dauphin Island, Alabama for the years 2000-2100. Colored dots indicate the estimates from NOAA (Sweet et al. 2017) and dashed lines indicate the estimates from the USACE sea level change calculator (version 2019.21; USACE 2019)

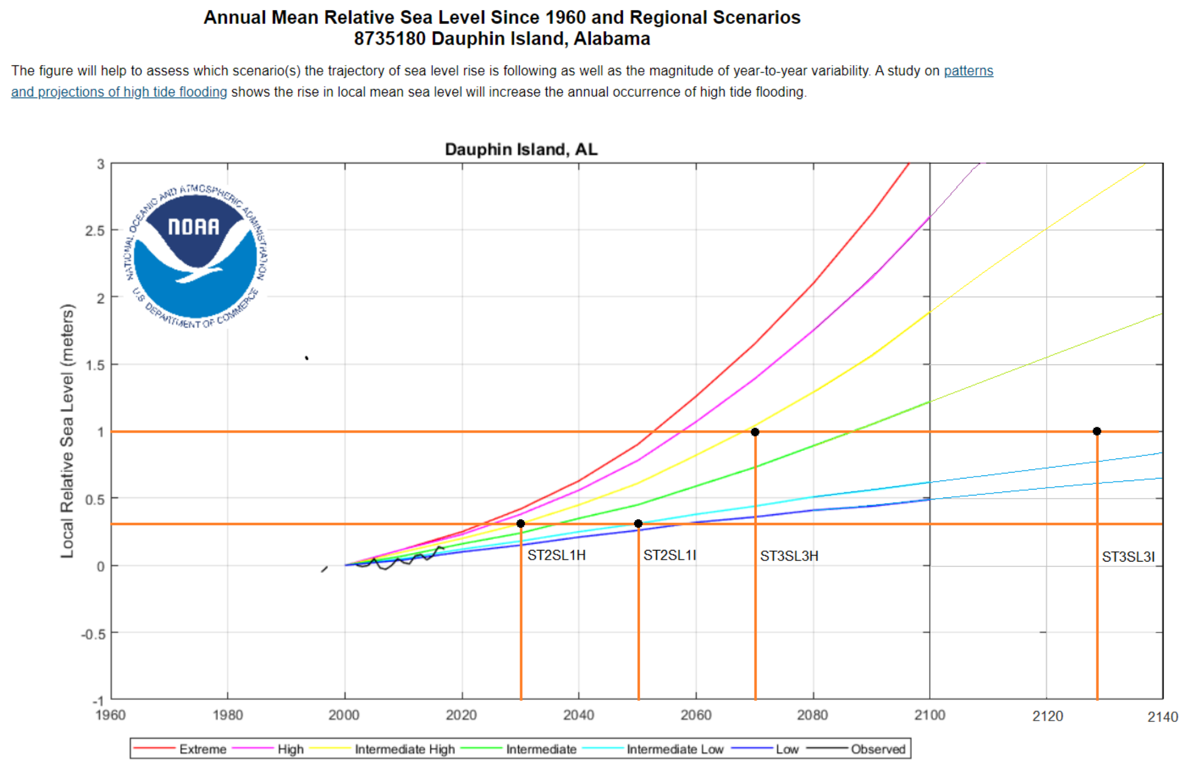

Figure 7. Annual Mean Relative Sea Level Rise (SLR) since 1960 and Regional Scenarios for Dauphin Island, Alabama (8735180). This figure illustrates predicted rates of sea level rise based on a moderate greenhouse gas scenario identified in Sweet et al. (2017). SLR estimates ranged from extreme (red line) to low (blue line); historical observations are represented (black line). The best fit NOAA sea level rise scenario that represented the USACE sea level rise scenarios for ALBIRA were estimated on the graph at the intersection of the orange horizontal (maximum sea level rise in meters for ALBIRA model scenarios) and vertical (terminal year used for ALBIRA estimates). Because year 2128 (STSL3I) was not included on the original graph obtained from NOAA, NOAA curves were extended to include 2100-2140 based on SLR estimates for 2080-2100. Accessed from the regional scenarios tab at: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?plot=scenario&id=8735180#tab50r

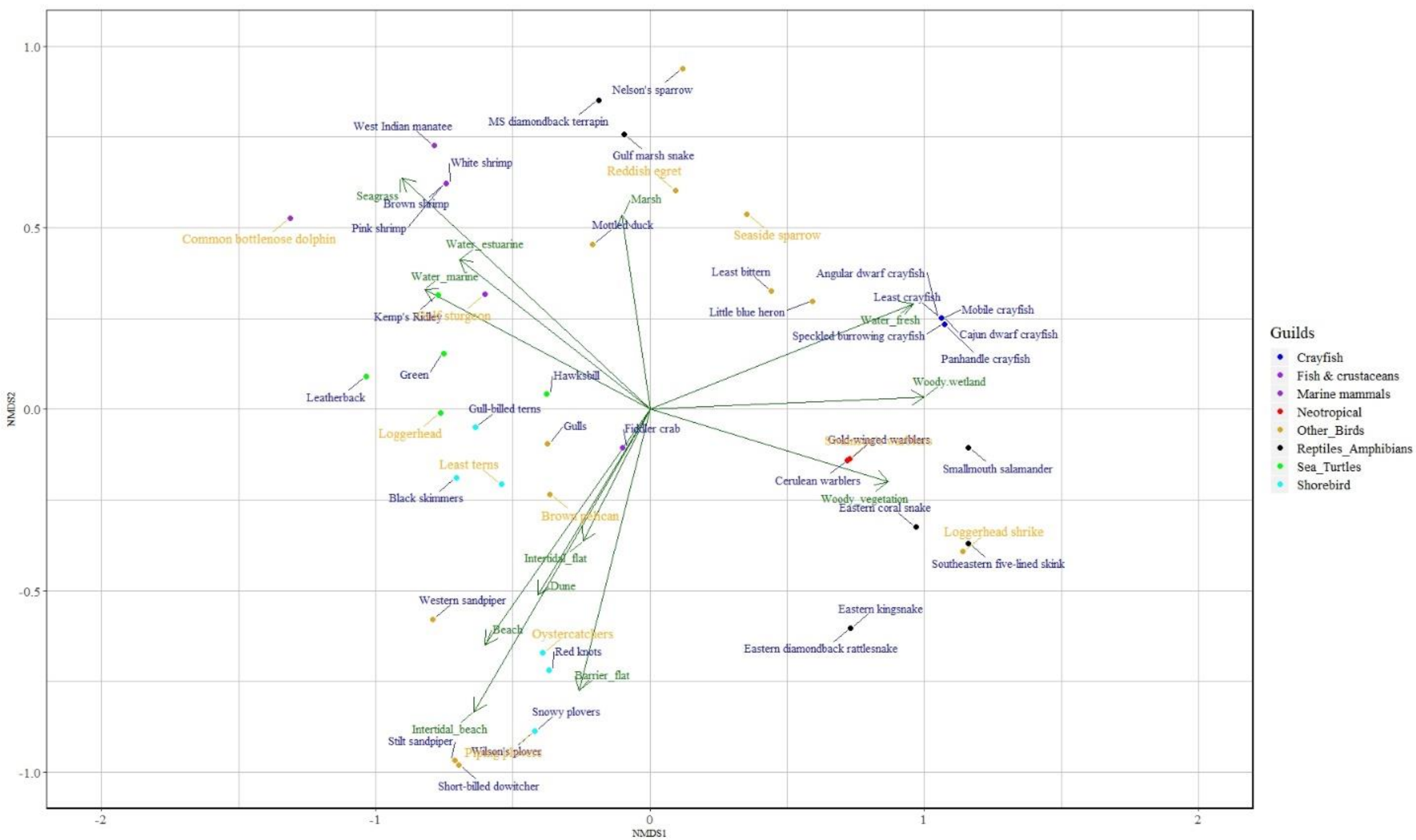

Figure 8. Results of the Non-metric Multi-dimensional Scaling (NMDS; total ordination stress indicated a moderately good fit at 0.15) for species and habitat. Species were identified by stakeholders and through published lists of species of concern. Surrogate species (in yellow) represent other species in habitat space (green arrows and labels), and were modeled in the Bayesian Belief Network for Alabama Barrier Island Restoration Assessment. Each taxa group is represented by a different colored dot (see the legend).

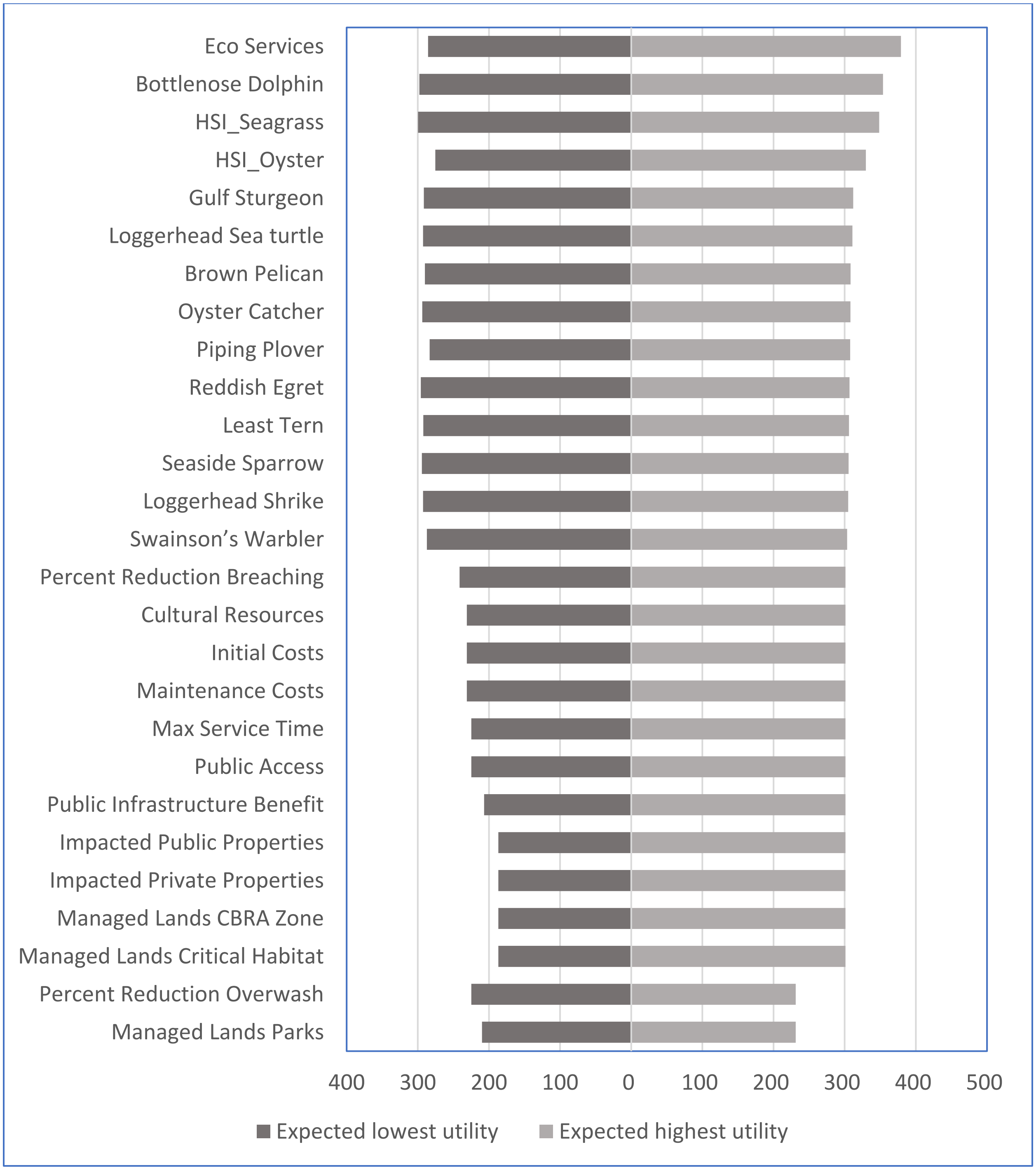

Figure 9. Tornado diagram displaying the results of the one-way sensitivity analysis for all state variables (listed on y axis) of the Bayesian Belief Network (BBN) for the Alabama Barrier Island Restoration Assessment (ALBIRA). Expected lowest utility values (dark gray) and highest utility values (light gray) are plotted on the x axis. The wider the bars, the more influential the state variable was on the optimal decision.

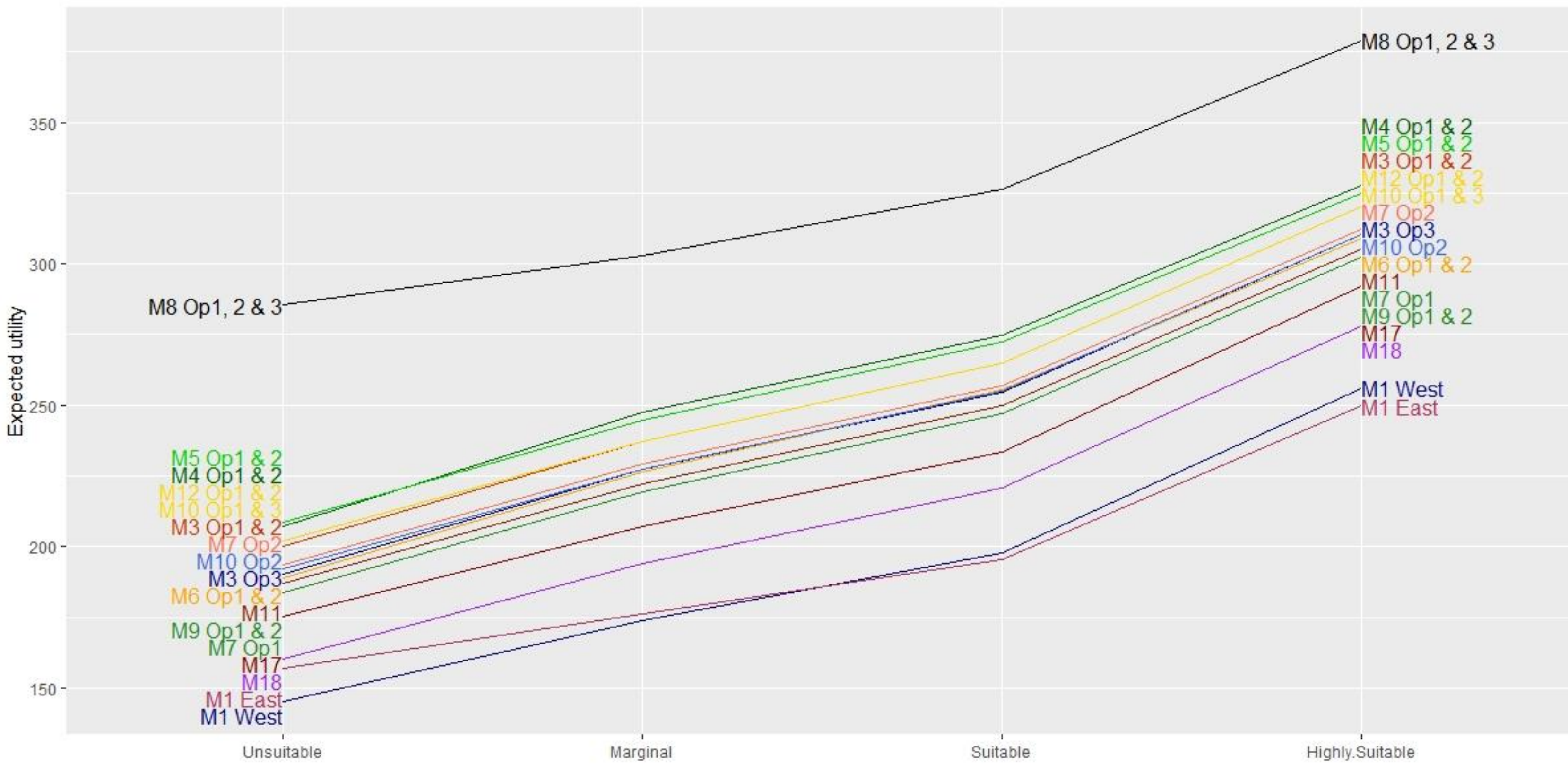

Figure 10. Response profile of the ecosystem services node from the Bayesian Belief Network for the Alabama Barrier Island Restoration Assessment. Expected values for each state are plotted for each restoration measure (colored labels listed on the graph; Table 1). The line with the highest expected values for all states (black line) is the optimal decision and does not change among states for this variable. The position of the colored lines and their matching labels represents rank of the expected value for restoration measures for the unsuitable and highly suitable states of this variable. Ranks among restoration measures across states varied slightly. Note in several instances, more than one restoration measure is assigned to one line.

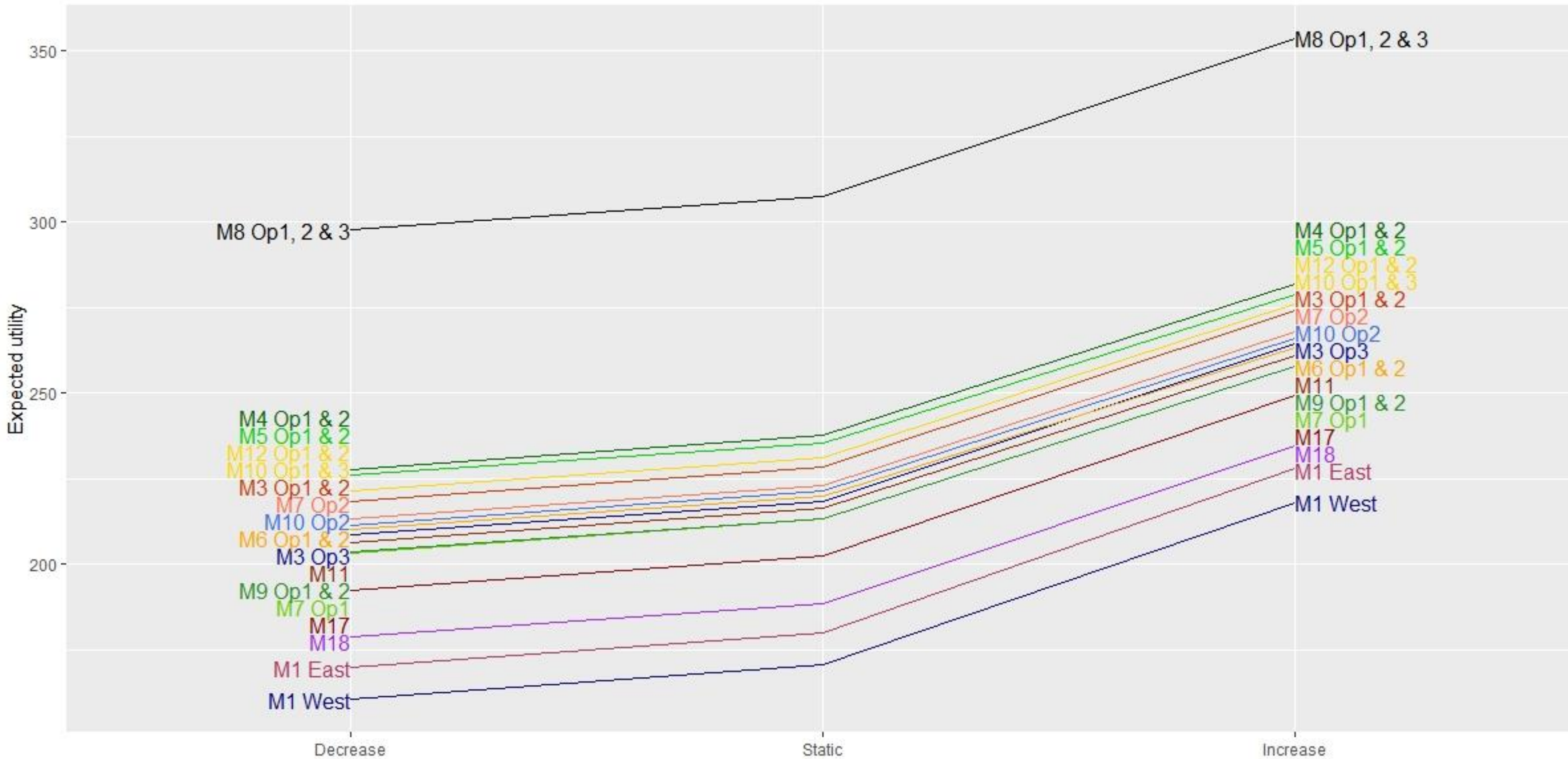

Figure 11. Response profile of the bottlenose dolphin node from the Bayesian Belief Network for the Alabama Barrier Island Restoration Assessment. Expected values for each state are plotted for each restoration measure (colored labels listed on the graph; Table 1). The line with the highest expected values for all states (black line) is the optimal decision and does not change among states for this variable. The position of the colored lines and their matching labels represents rank of the expected value for restoration measures for the unsuitable and highly suitable states of this variable. Ranks among restoration measures across states varied slightly. Note in several instances, more than one restoration measure is assigned to one line.

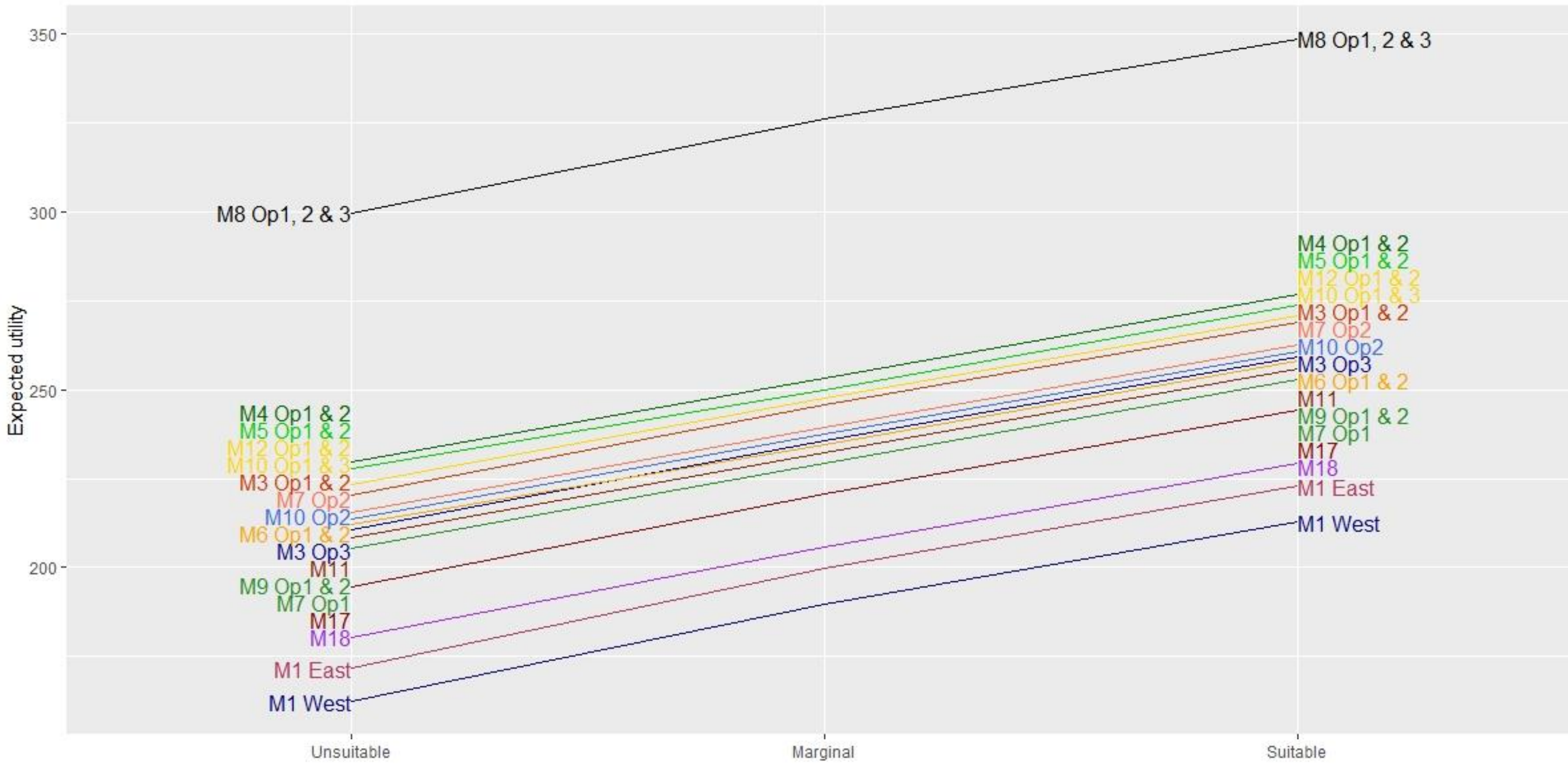

Figure 12. Response profile of the habitat suitability index (HSI) seagrass node from the Bayesian Belief Network for the Alabama Barrier Island Restoration Assessment. Expected values for each state are plotted for each restoration measure (colored labels listed on the graph; Table 1). The line with the highest expected values for all states (black line) is the optimal decision and does not change among states for this variable. The position of the colored lines and their matching labels represents rank of the expected value for restoration measures for the unsuitable and highly suitable states of this variable. Ranks among restoration measures across states varied slightly. Note in several instances, more than one restoration measure is assigned to one line

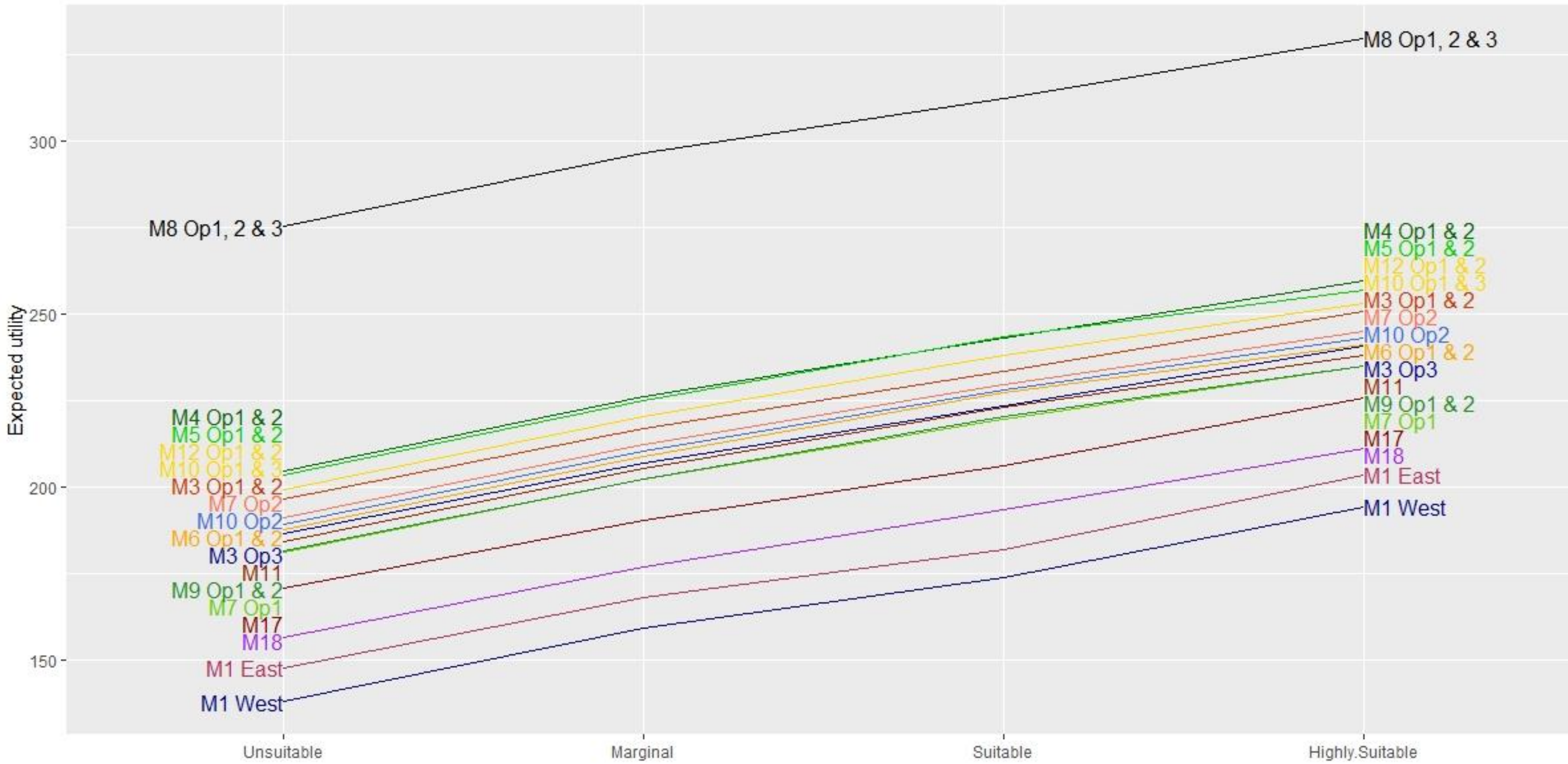

Figure 13. Response profile of the habitat suitability index (HSI) oyster node from the Bayesian Belief Network for the Alabama Barrier Island Restoration Assessment. Expected values for each state are plotted for each restoration measure (colored labels listed on the graph; Table 1). The line with the highest expected values for all states (black line) is the optimal decision and does not change among states for this variable. The position of the colored lines and their matching labels represents rank of the expected value for restoration measures for the unsuitable and highly suitable states of this variable. Ranks among restoration measures across states varied slightly. Note in several instances, more than one restoration measure is assigned to one line.

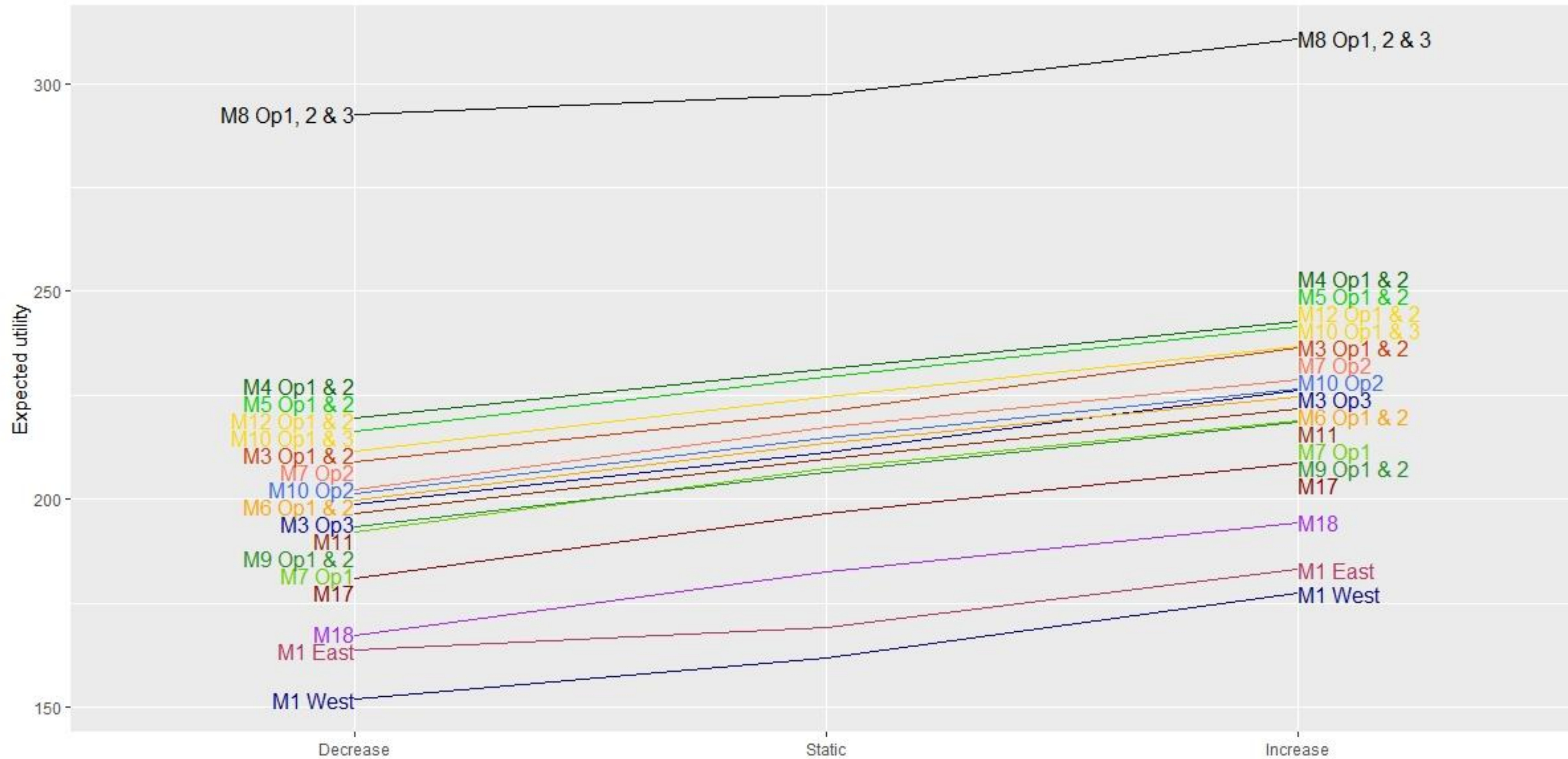

Figure 14. Response profile of the loggerhead sea turtle node from the Bayesian Belief Network for the Alabama Barrier Island Restoration Assessment. Expected values for each state are plotted for each restoration measure (colored labels listed on the graph; Table 1). The line with the highest expected values for all states (black line) is the optimal decision and does not change among states for this variable. The position of the colored lines and their matching labels represents rank of the expected value for restoration measures for the unsuitable and highly suitable states of this variable. Ranks among restoration measures across states varied slightly. Note in several instances, more than one restoration measure is assigned to one line.

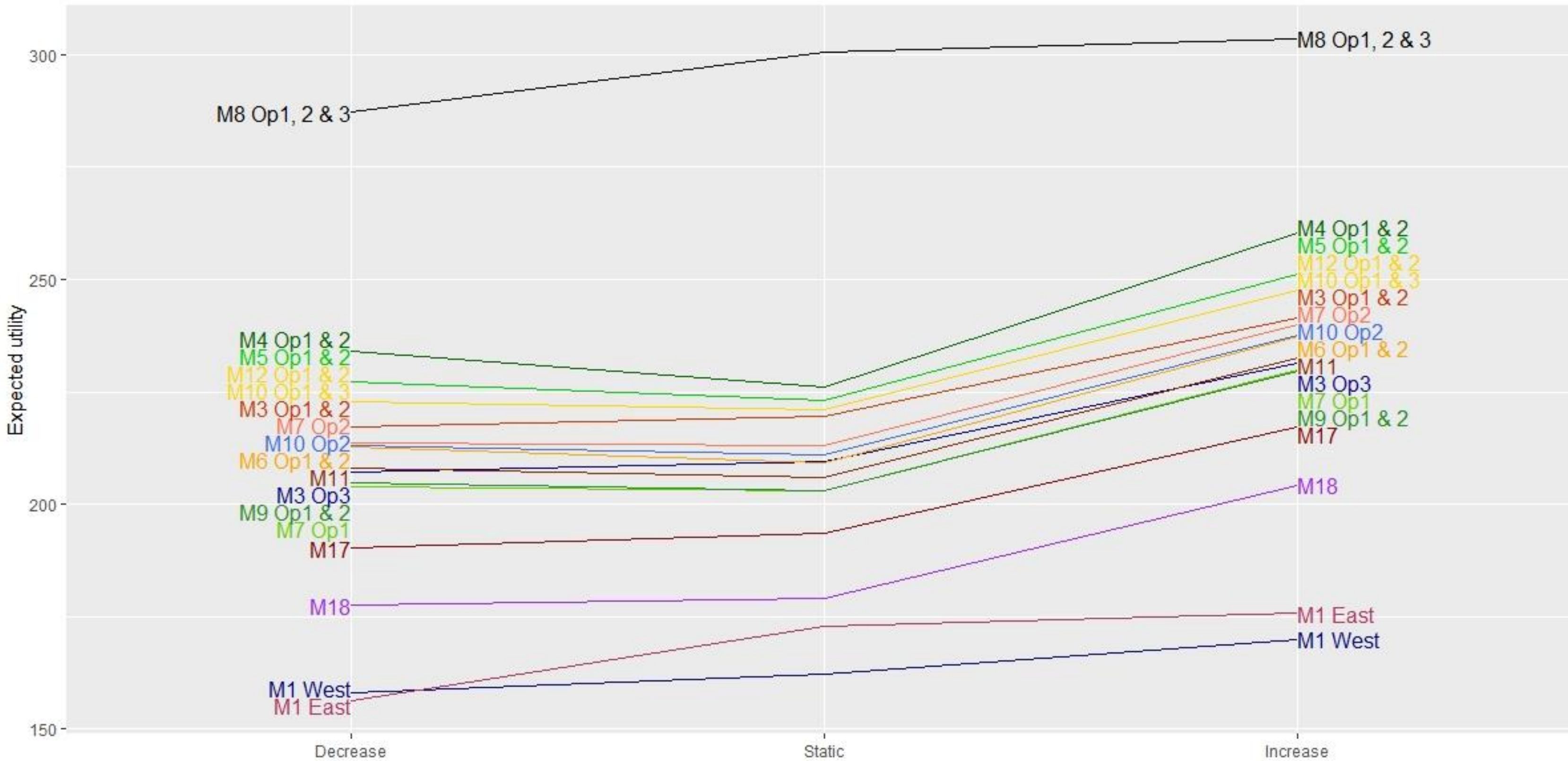

Figure 15. Response profile of the Swainson's warbler node from the Bayesian Belief Network for the Alabama Barrier Island Restoration Assessment. Expected values for each state are plotted for each restoration measure (colored labels listed on the graph; Table 1). The line with the highest expected values for all states (black line) is the optimal decision and does not change among states for this variable. The position of the colored lines and their matching labels represents rank of the expected value for restoration measures for the unsuitable and highly suitable states of this variable. Ranks among restoration measures across states varied slightly. Note in several instances, more than one restoration measure is assigned to one line.

Table 1. Descriptions of restoration measures (Mx notation corresponds to the measure naming convention in the Bayesian Belief Network (BBN) decision node) evaluated in the BBN for the Alabama Barrier Island Restoration Assessment (ALBIRA). The options (e.g., Opt 1-3) refer to different locations for obtaining materials for the restoration measure. Habitat and additional benefits provided by the measures are listed.

Restoration Measure	Habitat Benefit	Additional Benefits
Ebb Tidal Shoal Measures		
M3. Pelican Island Southeast Nourishment Opt-1 M3. Pelican Island Southeast Nourishment Opt-2 M3. Pelican Island Southeast Nourishment Opt-3	240 ac of intertidal beach and barrier flat; reduced loss of managed lands and piping plover critical habitat	Reduction in wave energy and shoreline erosion East End DI
M7. Sand Island Platform Nourishment and Sand Bypassing Opt-1 M7. Sand Island Platform Nourishment and Sand Bypassing Opt-2	127 ac of submerged offshore sand along ebb tidal shoal system; Directly feeds Pelican Island and Sand Island shoals	Reduction in shoal loss around Sand Island Lighthouse
Gulf Beach Measures		
M8. East End Beach and Dune Restoration Opt-1 M8. East End Beach and Dune Restoration Opt-2 M8. East End Beach and Dune Restoration Opt-3	Restores 35 ac beach and dune habitat	Reduced loss of managed lands; storm risk reduction to an additional 50 ac of beach, dune, woody vegetation and freshwater lakes
M5. West End Beach and Dune Restoration (No Buyouts) Opt-1 M5. West End Beach and Dune Restoration (No Buyouts) Opt-2	Restores 200 acres beach and dune habitat; reduced loss of piping plover critical habitat	Storm risk reduction to an additional 100+ ac of beach, dune, intertidal flats and intertidal marsh
M4. West End Beach and Dune Restoration (Voluntary Buyouts) Opt-1 M4. West End Beach and Dune Restoration (Voluntary Buyouts) Opt-2	Restores 200 acres beach and dune habitat; reduced loss of piping plover critical habitat	Storm risk reduction to an additional 100+ ac of beach, dune, intertidal flats and intertidal marsh; storm damage reduction to 225 residential structures
M4. West End/Katrina Cut Beach and Dune Restoration (Voluntary Buyouts) Opt-1 M4. West End/Katrina Cut Beach and Dune Restoration (Voluntary Buyouts) Opt-2	Restores 450 ac beach and dune habitat; reduced loss of managed lands and piping plover critical habitat	Storm risk reduction to an additional 280+ ac of beach, dune, intertidal flats and itnertidal marsh; storm damage reduction to 225 residential structures
M17. Katrina Cut Structure Removal	Restores 27 ac of back barrier flat, intertidal flat and intertidal beach; restores piping plover critical habitat	Allows breaching in a natural area per natural processes for maintaining barrier island (under ST3SL3)
Back-Barrier and Marsh Restoration Measures		
M9. 2010 Borrow Pits Restoration Opt-1 M9. 2010 Borrow Pits Restoration Opt-2	Restores intertidal and barrier flat habitat; increases back barrier meadow and wetlands, restores piping plover critical habitat	Provides platform for migration of intertidal marsh under rising SL

Table 1. Continued.

M10. Marsh Habitat Restoration Behind Katrina Cut Opt-1 M10. Marsh Habitat Restoration Behind Katrina Cut Opt-2 M10. Marsh Habitat Restoration Behind Katrina Cut Opt-3	Restores 75 ac intertidal marsh habitat; reduced loss of managed lands and piping plover critical habitat	Reduces lee side damage to Katrina Cut structure
M12. Aloe Bay Beneficial Use Marsh Restoration Opt-1 M12. Aloe Bay Beneficial Use Marsh Restoration Opt-2	Restores 6 ac intertidal marsh	Reduces lee side shoreline erosion in project area
M11. Graveline Bay Marsh Restoration	Restores 25 ac intertidal marsh	Increase fish and shellfish habitat
M18. West End Back-Barrier Herbaceous Dune Plant Restoration	Restores 21 ac herbaceous dune habitat; Restores piping plover critical habitat	Rebuilds island elevation

Table 2. Descriptions of land acquisition measures, habitat benefits, and additional benefits evaluated in the Bayesian Belief Network for Alabama Barrier Restoration Assessment.

Measure	Habitat Benefit	Additional Benefits
Land Acquisition Measures		
West End Land Acquisition	720 ac of beach, dune, scrub/shrub, tidal flats and pools, salt meadows and marsh	Increase habitat for multiple species
Mid-Island Land Acquisition and Management Phase I	2.5 ac of beach and dune	Increase habitat for multiple species
U.S. Coast Guard Property Acquisition	7.5 ac of scrub/shrub, dune, maritime forest and beach	Increase habitat for multiple species
Dauphin Island 39 Parcel Property Acquisition: Parcel A – West End	518 ac of open water in MS Sound, overwash sand adjacent to residential property, some low dune vegetation, sand ponds from Deepwater Horizon	Increase habitat for multiple species Increase fish and shellfish habitat
Dauphin Island 39 Parcel Property Acquisition: Parcel B – Graveline Bay	340 ac of intertidal wetlands, intertidal flats and open water	Increase fish and shellfish habitat
Dauphin Island 39 Parcel Property Acquisition: Parcel C – Aloe Bay	76 ac of shallow open water in MS Sound	Increase fish and shellfish habitat
Dauphin Island 39 Parcel Property Acquisition: Parcel D – Little Dauphin Island Bay	14 ac of shallow open water in MS Sound	Increase fish and shellfish habitat
Dauphin Island 39 Acquisition: Parcel E – East End	4 ac of dune and commercial property	Increase habitat for multiple species
Tupelo Gum Swamp Land Acquisition	10 ac of Tupelo Gum wetlands and freshwater wetlands	Increase habitat for multiple species Increase freshwater habitat
Gorgas Swamp Land Acquisition	10 ac of Tupelo Gum wetlands	Increase habitat for multiple species Increase freshwater habitat
Steiner Property Acquisition	9 ac of beach and dune	Increase habitat for multiple species

Table 3. List of restoration model scenarios (model scenarios node; Bayesian Belief Network) that were used to generate data for the habitat composition and water depth nodes. The model scenarios (R0-R8) included a combination of associated restoration measures (M1-M18; decision node) that were spatially distinct in the model domain (see Table 1 for descriptions of associated restoration measures). Data sources are reported; data were also used to inform multiple child nodes in the BBN for the Alabama Barrier Island Restoration Assessment.

Variable	Data Source	Model Scenario	Associated Measures
Restoration Model Scenarios	USACE and USGS; Model scenarios were combinations of Measures that were modeled independently for island/sound morphology (Mickey et al. 2020).and habitat models (Enwright et al. 2020)	R0 West End No Action	M1 No Action Measure West
		R0 East End No Action	M1 No Action Measure East
		R1 Katrina Cut Removal	M17 Katrina Cut Remove Mound
		R2 Pelican Island	M3 Op 1, 2, and 3 Pelican Island SE Nourishment
		R3 Sand Island	M7 Op 1 and 2 Sand Island Nourishment
		R4 West End WOBO*	M5 Op 1 and 2 West End Beach and Dune Nourishment WOBO
		R4 East End Dune Restoration	M8 Op 1, 2 and 3 East End Beach and Dune Restoration
		R5 Back Barrier Options	M9 2010 Borrow Pits Restoration, M10 Marsh Habitat Restoration behind Katrina Cut, M11 Graveline Bay Marsh Restoration Aloe Bay Beneficial Use Marsh Restoration, M12 Aloe Bay Beneficial Use Marsh Restoration
		R6 West End WBO**	M6 West End Beach and Dune Nourishment WBO
		R7 West End Katrina Cut WBO**	M4 West End and Katrina Cut Beach and Dune Nourishment with Buyout
		R8 West End Back Barrier Dune Restoration	M18 West End Backbarrier Herbaceous Dune Plant Restoration

*Without buy-outs refers to not purchasing private land in the area of the restoration measure

**With buy-outs refers to purchasing private land in the area of the restoration measure

Table 4. Probabilities associated with the storm and sea level rise scenarios used for in the Bayesian Belief Network (BBN) for Alabama Barrier Island Restoration Assessment (ALBIRA) model scenarios [P_{st}; Mickey et al (2020), Table 2, page 19.] and sea level rise (P_{sl}) probabilities for each scenario. The storm and sea level rise node was parameterized with estimated probabilities of storms (ST) and sea level rise (SL) occurring during the 10 year model horizon. Normalized probabilities were computed by multiplying P_{st} and P_{sl} [(estimated for each SL scenario from published National Oceanic and Atmospheric Association (NOAA) curves for an intermediate greenhouse gas model (RCP4.5) for Dauphin Island**; Figures 6 and 7)], summing the products (total probability), and normalizing the data by dividing each scenario's product by the sum and multiplying by 100. See text for more detail.

ST/SL Scenarios	P_{st}*	Best fit NOAA sea level curve	P_{sl} RCP4.5**	Total Probability ST/SL	Normalized Probability ST/SL
ST2SL1H	0.57	Intermediate-high	0.005	0.00285	0.45
ST2SL1I	0.57	Intermediate-low	0.730	0.4161	65.83
ST3SL3H	0.29	Intermediate-high	0.005	0.00145	0.23
ST3SL3I	0.29	Intermediate-low	0.730	0.2117	33.49
Total	-		-	0.6321	100.00

*Mickey et al (2020)
**Sweet et al. (2020)

Table 5. Habitat variables, discretization methods used to assign data to states, and node states with bin definition for the Bayesian Belief Network (BBN) developed for the Alabama Barrier Island Restoration Assessment (ALBIRA).

Variable	Discretization Methods	State
Habitat Composition	Probability distribution of each habitat type in the modeling domain* for each storm and sea level rise (ST/SL) and restoration model scenario at Y10**; Enwright et al. 2020. Habitat composition informed species response to changes in habitat.	Intertidal flat Intertidal beach Marsh Beach Dune Barrier flat Woody vegetation Woody wetland Water fresh
Habitat Delta	Percent change over the 10 year modeling horizon of habitat types exhibiting loss, gain or static states over time; Enwright et al. 2020. The states partially informed the ecosystem services node.	High loss (≤ -50) Moderate loss (> -50 - ≤ -5) Static (> -5 and < 5) Moderate gain (≥ 5 and ≤ 50) High gain (≥ 50)
Water Depth	Probability distribution of each depth state in the modeling domain* for each ST/SL and restoration model scenario. Water depth informed species response to changes in water depth. Bins of 2m from 0 to 12m below sea level (bsl) were parameterized with bathymetry data provided by Mickey et al. 2020	bsl 12m bsl 10m bsl 8m bsl 6m bsl 4m bsl 2m bsl 0m
Water Depth Delta	Percentage change over 10 year modeling horizon. Percentiles of depths exhibiting loss, gain or static conditions over time. These node states were determined by the parent nodes of water depth, ST/SL and model scenarios.	High loss (≤ -15) Moderate loss (> -15 - ≤ -1) Static (> -0.9 and < 0.9) Moderate gain (≥ 1 and ≤ 15) High gain (≥ 15)

*Model domain is 2.5 km from the historic 1940-2015 shorelines of Dauphin Island and includes the island morphology (Enwright et al. 2020)
**Y10 is year 10 from the model simulations (Enwright et al. 2020)

Table 6. Variables associated with ecological function, discretization methods for determining states, state bin descriptions, and utility values for the states. These nodes informed the Maximize Sustainability utility node in the Bayesian Belief Network (BBN) developed for the Alabama Barrier Island Restoration Assessment (ALBIRA).

Variable	Discretization Methods	State	Utility
HSI_Oyster HSI_Seagrass	Probability distribution for habitat suitability indices (HSI) meeting the state conditions reported in Wang et al.(2020a) and Wang et al. (2020b) for model and ST/SL scenarios. They calculated HSI for oysters and seagrasses over the extent of the modeling space for ALBIRA.*	Unsuitable (<0.3)	0
		Marginal (0.3-0.5)	10
		Suitable (0.5-0.7)	15
		Highly suitable (>0.7)	25
Ecosystem Services List	Top five ecosystem services provided for habitats. Overall tally scores (in parentheses) were calculated from importance values elicited from experts for each ecosystem service and habitat and ranked; see Appendix A for breakdown of values by habitat.	Fish Habitat (18)	n/a
		Storm Buffer (14)	n/a
		Biodiversity (19)	n/a
		Sediment/Nutrient reduction (20)	n/a
		Water quality enhancement (21)	n/a
Ecosystem Services	Percentiles of scores for ecosystem services that met the criteria for four quartile suitability bins. Calculated by combining values for ecosystem services provided by habitat type, HSI oyster, HSI seagrass, and managed lands critical habitat.	Unsuitable	0
		Marginal	10
		Suitable	15
		Highly suitable	25
Managed Lands Critical Habitat	Percent change for Critical Habitat** area impacted by model and ST/SL scenarios from Y0-Y1. Critical habitat represents area of managed lands falling under USFWS designated piping plover critical habitat for model and ST/SL scenarios from model output shape files; Mickey et al. (2020).	High gain (≥ 50)	25
		Moderate gain (≥ 5 and ≤ 50)	20
		Static (> -5 and < 5)	15
		Moderate loss (> -50 and ≤ -5)	5
		High loss (≤ -50)	0

*Model extent is 2.5 km from historical 1940-2015 shoreline of Dauphin Island and includes the island morphology (Enwright et al. 2020)
**Critical habitat for piping plover (*Charadrius melodus*) delineated (DOI 2001).

Table 7. Habitat values for each ecosystem service based on scoring by experts during an elicitation for the Alabama Barrier Island Restoration Assessment. Values represent the tallied number of votes from experts during an elicitation and represent the value of each habitat for providing the listed ecosystem service. The habitats ultimately represented in the Bayesian Belief Network (BBN) differed from the habitats considered in the initial elicitation (bold text); equivalent habitats from the Enwright et al. (2020) model are listed (BBN habitat equivalent plain text).

Habitat	**Maritime forest**	**Submerged aquatic vegetation**	**Freshwater wetland**	**Streams/riparian buffer**	**Intertidal marshes and flats**	**Beaches and dunes**	**Oyster reefs**
BBN habitat equivalent*	Woody vegetation	HSI_Seagrass	Woody wetland	Water fresh	Marsh/intertidal flat/intertidal beach/barrier flat	Beach/dune	HSI_Oyster
Fish habitat	0	5	3	2	4	0	4
Storm buffer	2	1	1	0	4	5	1
Biodiversity	2	4	1	2	5	2	4
Sediment/nutrient retention	1	5	2	1	5	4	2
Water quality enhancement	1	4	3	1	6	1	5

*from Enwright et al. (2020)

Table 8. Habitat delta, habitat suitability index (HSI) seagrass and HSI oyster values which were used in combination with values from Table 7 to inform the Ecosystem Services node (Table 6) in the Bayesian Belief Network for the Alabama Barrier Island Restoration Assessment

State	Value
Habitat Delta state	
High loss	0
Moderate loss	1
Static	2
Moderate gain	3
High gain	4
HSI seagrass and HSI oyster states	
Unsuitable	0
Marginal	1
Suitable	2
Highly suitable	3

Table 9. Descriptions of primary habitat affinities for surrogate species from faunal groups included in the Bayesian Belief Network for the Alabama Barrier Island Restoration Assessment. The surrogate species represented other species of interest to stakeholders with affinity to specific primary habitats. Selection of surrogate species was informed by a Non-metric Multi-dimensional Scaling (NMDS) analysis, published literature and value to stakeholders.

Surrogate Species	Group	Primary Habitat	Represented Species
Least tern	Shorebird	beach, dune, barrier flat, water - fresh, estuarine and marine	black skimmer, gull-billed terns
Piping plover	Shorebird	beach, dune, barrier flat, intertidal beach, intertidal flat	snowy plover, Wilson's plover, short-billed dowitcher, stilt sandpiper
Oystercatcher	Shorebird	beach, intertidal beach, intertidal flat	red knot, western sandpiper
Swainson's warbler	Neotropical bird	woody vegetation, woody wetland	gold-winged warblers, cerulean warblers, least crayfish, angular dwarf crayfish, cajun dwarf crayfish, speckled burrowing crayfish, panhandle crayfish, mobile crayfish
Seaside sparrow	Other bird	marsh, intertidal flat	least bittern, little blue heron
Reddish egret	Other bird	intertidal flat	mottled duck, gulf marsh snake, MS diamondback terrapin, Nelson's sparrow
Loggerhead shrike	Other bird	woody vegetation, woody wetland	southeastern five-lined skink, eastern coral snake, eastern kingsnake, eastern diamondback rattlesnake, smallmouth salamander
Brown pelican	Other bird	water - estuarine and marine, beach	gulls, fiddler crab
Gulf sturgeon	Fish & crustaceans	water - estuarine and marine	brown shrimp, pink shrimp, white shrimp, West Indian manatee
Loggerhead	Sea turtles	beach, dune, seagrass, water - estuarine and marine, marsh	green sea turtle, leatherback sea turtle, Kemp's Ridley sea turtle, hawksbill sea turtle
Common bottlenose dolphin	Marine mammals	water - marine	

Table 10. Habitat affinity values elicited from experts during the Alabama Barrier Island Restoration Assessment. Values were determined using a Likert scale (0-5) where 0 was least and 5 was most valuable for individual species. Appendix A, Table A4 reports these values for all species considered in ALBIRA.

Species*	Group	Beach	Dune	Woody vegetation	Woody wetland	Barrier flat	Intertidal beach	Intertidal flat	Marsh	Seagrass	Water fresh	Water estuarine	Water marine
Least tern	Shorebird	5	5	0	0	5	0	0	0	0	5	5	5
Piping plover	Shorebird	5	5	0	0	5	5	5	0	0	0	0	0
Oystercatcher	Shorebird	5	2	0	0	0	5	5	3	0	0	0	0
Swainson's warbler	Neotropical bird	1	1	5	4	1	0	0	2	0	2	0	0
Seaside sparrow	Other bird	0	0	3	1	0	0	4	5	0	0	0	0
Reddish egret	Other bird	0	0	1	1	0	0	5	2	0	0	3	0
Loggerhead shrike	Other bird	0	0	5	4	0	0	0	0	0	0	0	0
Brown pelican	Other bird	4	2	3	2	0	4	0	0	0	0	5	5
Gulf sturgeon	Fish & crustaceans	0	0	0	0	0	3	3	0	0	2	4	4
Loggerhead sea turtle	Sea turtles	5	5	0	0	0	3	0	4	5	0	5	5
Common bottlenose dolphin	Marine mammals	0	0	0	0	0	0	0	0	2	0	3	5

*Based on a non-metric multi-dimensional scaling (NMDS) of habitat affinities for 48 species (see Figure 8)

Table 11. Habitat value and Loss/Gain states from the habitat delta node in Bayesian Belief Network (BBN) for the Alabama Barrier Island Restoration Assessment. Habitat values were determined using a Likert scale (0-5) where 0 was least and 5 was most valuable for species. Probability of population response (Increase, Static, Decrease) was informed using the following hypothetical relations between habitat importance and population response state for each surrogate species.

Habitat Value State	Probability of Population Response		
5	**Increase**	**Static**	**Decrease**
High Loss	0	0	1
Moderate Loss	0	0.5	0.5
Static	0.1	0.8	0.1
Moderate Gain	0.5	0.5	0
High Gain	1	0	0
4	**Increase**	**Static**	**Decrease**
High Loss	0	0.2	0.8
Moderate Loss	0	0.6	0.4
Static	0.05	0.9	0.05
Moderate Gain	0.4	0.6	0
High Gain	0.8	0.2	0
3	**Increase**	**Static**	**Decrease**
High Loss	0	0.4	0.6
Moderate Loss	0	0.7	0.3
Static	0	1	0
Moderate Gain	0.3	0.7	0
High Gain	0.6	0.4	0
2	**Increase**	**Static**	**Decrease**
High Loss	0	0.6	0.4
Moderate Loss	0	0.8	0.2
Static	0	1	0
Moderate Gain	0.2	0.8	0
High Gain	0.4	0.6	0
1	**Increase**	**Static**	**Decrease**
High Loss	0	0.8	0.2
Moderate Loss	0	0.9	0.1
Static	0	1	0
Moderate Gain	0.1	0.9	0
High Gain	0.2	0.8	0

Table 12. Surrogate species, International Union for Conservation of Nature listing and population trend (IUCN 2020), predicted population state, and utility values. Higher values were assigned to threatened and endangered species or species with declining population trends Utility values were used to inform the coastal resources utility node in the Bayesian Belief Network for Alabama Barrier Island Restoration Assessment. The utility value for all combinations of species state were summed for the total utility (maximum utility was 100 which was equal to the summed values of the increase state (bold) for the species) see text for more information).

Species	IUCN Listing and IUCN Population Trends	State	Utility
Seaside Sparrow	Least Concern	Increase	**8**
	Increasing	Static	4
		Decrease	0
Brown Pelican	Least Concern	Increase	**8**
	Increasing	Static	4
		Decrease	0
Oyster Catcher	Least Concern	Increase	**8**
	Stable	Static	4
		Decrease	0
Least Tern	Least Concern	Increase	**12**
	Decreasing	Static	6
		Decrease	0
Swainson’s warbler	Least Concern	Increase	**12**
	Decreasing	Static	6
		Decrease	0
Piping Plover	Near Threatened	Increase	**16**
	Increasing	Static	8
		Decrease	0
Reddish Egret	Near Threatened	Increase	**16**
	Increasing	Static	8
		Decrease	0
Loggerhead Shrike	Near Threatened	Increase	**20**
	Decreasing	Static	10
		Decrease	0

Table 13. Surrogate species, habitat suitability index (HSI), International Union for Conservation of Nature listing and population trend (IUCN 2020), other justifications (i.e., Federally protected species; important habitat), predicted population state, and utility values. Higher values were assigned to threatened and endangered species or species with declining population trends Utility values were used to inform the coastal resources utility node in the Bayesian Belief Network for Alabama Barrier Island Restoration Assessment. The utility value for all combinations of species and HSI state were summed for the total utility (maximum utility was 100 which was equal to the summed values of the increase state (value in bold) for the species) see text for more information).

Species Habitat Suitability Index	IUCN Listing, IUCN Population Trends, and other listings/justifications	State	Utility
Loggerhead Sea Turtle	Near Threatened	Increase	**15**
	Unknown	Static	7.5
		Decrease	0
Bottlenose Dolphin	Least Concern	Increase	**15**
	Unknown	Static	7.5
		Decrease	0
Gulf Sturgeon	Near Threatened	Increase	**20**
	Increasing	Static	10
	Federally listed as Threatened	Decrease	0
HSI Seagrass	Important habitat for multiple coastal and marine species	Highly Suitable	**25**
HSI Oyster		Suitable	20
		Marginal	10
		Unsuitable	0

Table 14. Variables important to stakeholders that may have been impacted by restoration measures and severity and rates of storminess/sea level rise (ST/SL) scenarios. Methods used to inform states, node states with bin definitions, and utility values for the Bayesian Belief Network (BBN) developed for the Alabama Barrier Island Restoration Assessment (ALBIRA). Higher utility values were assigned to higher valued states in each node to inform the maximize social acceptance utility node. The utility value for all combinations variables and states were summed for the total utility (maximum utility was 100 which was equal to the summed values of highest valued state (value in bold, see text for more information).

Variable	Discretization Methods	State	Utility
Cultural Resources	Presence or absence of National Registrar of Historic Sites in the area affected by each measure. Cultural sites include the Sand Island Lighthouse located offshore along the Mobile ebb tidal delta and Fort Gaines located on eastern terminal end of the island.	Lighthouse	**15**
		Fort	15
		No	0
Managed Lands Parks	Indicates the number of local, county, state or federally managed land/parks located in the area of the proposed measure. Sources include Dauphin Island Park and Beach Board, the Nature Conservancy, Mobile County, Alabama Department of Conservation and Natural Resources, Mobile Bay National Estuary Program and United States Fish and Wildlife Service owned lands. (Mickey et al. 2020; Mobile County GIS Department 2020*)	Benefit 0	0
		Benefit 1	2
		Benefit 2	5
		Benefit 3	7
		Benefit 4	**10**
Percent Reduction Overwash	Represents the percent reduction in overtopping occurrence derived from the Xbeach model output (Mickey et al. 2020). Calculations include the total number of hours that water levels were greater than the maximum island elevation at vulnerable areas susceptible to overwash.	High (> 75%)	**10**
		Medium (25-75%)	5
		Low (< 25%)	0
Percent Reduction Breaching	Represents the estimated percent of reduced breaching events from each model run compared to no-action case (Mickey et al. 2020).	Reduced 100 Percent	**10**
		Reduced 40 Percent	4
		Reduced 0 Percent	0
Managed Lands Critical Habitat Managed Lands CBRA Zone	Percent of Critical Habitat** and CBRA*** Zone Land area impacted by restoration model and ST/SL scenarios. Critical habitat represents acres of managed lands falling under Department of Interior (2001) designated piping plover critical habitat. CBRA zone includes acres of managed lands falling under the USFWS designated CBRA. USACE estimations from model output shapefiles; Mickey et al. (2020).	High gain (≥ 50)	**10**
		Moderate gain (≥ 5 and ≤ 50)	7
		Static (> -5 and < 5)	5
		Moderate loss (> -50 and ≤ -5)	2
		High loss (≤ -50)	0

Table 14.-continued

Impacted Private Properties Impacted Public Properties	Values are percent change (gain/loss) in area of properties for each alternative and model scenario from Y0 to Y10. Calculated area of public and private properties were based on Mobile County parcel data located above the mean high water line using the digital terrain model output from Mickey et al. (2020) and shape files from Mobile County GIS Department (2020)*.	High gain (≥ 15)	**15**
		Moderate gain (≥ 1 and ≤ 15)	12
		Static (> -0.9 and < 0.9)	7
		Moderate loss (> -15 and ≤ -1)	3
		High loss (≤ -15)	0
Maximum Service Time	Parameterized based on how long (in years) it would take to incur positive restoration benefits and the amount of additional maintenance required to maximize benefits. Low - benefits within 5 years with significant maintenance; Medium - benefits within 5 years with minimal maintenance; High - immediate benefits with minimal maintenance.	Low	0
		Medium	5
		High	**10**

*https://www.mobilecountyal.gov/government/gis-mapping

**Critical habitat for Piping Plover delineated by USFWS

***CBRA - Coastal Barrier Resources Act

Table 15. Variables with associated costs relative to restoration measures and severity and rates of storminess/sea level rise (ST/SL) scenarios. Methods used to inform states, node states with bin definitions, and utility values for the Bayesian Belief Network (BBN) developed for the Alabama Barrier Island Restoration Assessment (ALBIRA). Higher utility values were assigned to higher valued states in each node to inform the minimize cost utility node. The utility value for all combinations variables and states were summed for the total utility (maximum utility was 100 which was equal to the summed values of highest valued state (value in bold, see text for more information).

Variable	Discretization Methods	State	Utility
Initial Cost	Initial cost represents the cost to implement the proposed measure with the given option of acquiring material. Cost estimates include design, management and 10% contingency (USACE 2020).	Low Acceptable (<$40 million)	**20**
		High Acceptable ($40-100 million)	10
		Unacceptable (>$100 Million)	0
Maintenance Cost	Maintenance cost represents the estimated cost to maintain the proposed measure with the given option of acquiring materials over a period of 20 years* (USACE 2020).	Low (<$10 million)	**20**
		Intermediate ($10- 40 million)	10
		High (>$50 million)	0
Public Access	Public access, such as parking areas, access points and facilities, were determined based on Mobile County parcel shapefile data**	Yes	**15**
		No	0
Public Infrastructure Benefit	Digital terrain model output from Mickey et al. (2020) was evaluated for potential loss of land through erosion or reduced debris removal during overtopping events.	Yes	**15**
		No	0
Cultural Resources	Presence or absence of National Registrar of Historic Sites in the area affected by each measure. Cultural sites include the Sand Island Lighthouse located offshore along the Mobile ebb tidal delta and Fort Gaines located on eastern terminal end of the island.	Lighthouse	**15**
		Fort	15
		No	0
Impacted Private Properties	Values reflect the percent change in acreage of private properties for each model and ST/SL scenario from Y0 to Y10.***Calculated area of private properties were based on Mobile County parcel data located above the mean high water line using the digital terrain model output from Mickey et al. (2020) that indicated potential change in land under each model and ST/SL scenarios.	High Loss	0
		Moderate Loss	3
		Static	7
		Moderate Gain	12
		High Gain	**15**

*Stakeholders defined time frame for estimating the maintenance costs associated with each measure (20 years)
**https://www.mobilecountyal.gov/government/gis-mapping)
***Y0 is year 0 and Y10 is year 10 in model domain.

Table 16. Individual and overall utility for assessment of the conservation value for parcels that may be purchased on Dauphin Island, Alabama. These values were used to inform the land conservation utility node for the Bayesian Belief Network (BBN) developed for the Alabama Barrier Island Restoration Assessment (ALBIRA) Metrics used to calculate utility were: Development (0,1); Scarcity (0-5; where 0 was least scarce and 5 was most scarce) based on habitat composition; Acreage utility (proportion of total available x 100); and Juxtaposition? (0,1; was the parcel adjacent to land already in conservation). Overall utility was the sum of the individual scores and Scaled utility normalized the data between 0-100.

Property	Development?	Scarcity	Acreage utility	Juxtaposition?	Overall utility	Scaled utility
Mid island phase I	1	3	1	1	6	13
Tupelo Gum Swamp	1	5	1	1	8	17.4
Gorgas Swamp	0	5	1	1	7	15.2
Steiner	1	5	1	1	8	17.4
West end	0	5	40	1	46	100
Coast Guard	1	1	1	1	4	8.7
DI39 West end	0	5	27	1	33	71.7
Graveline Bay	0	5	18	1	24	52.2
Aloe Bay	0	0	4	1	5	10.9
Little DI and Bay	0	0	7	1	8	17.4
East end	1	1	1	0	3	6.5

Table 17. Cost bins, cost states, and utility values for purchasing land on Dauphin Island, Alabama. These values were used to inform the minimize cost utility node for the Bayesian Belief Network (BBN) developed for the Alabama Barrier Island Restoration Assessment (ALBIRA. Each property was assigned a state and a utility was assigned and added to the utility score from the conservation value utility node.

Cost	State	Utility
≤ \$400,000	Lowest	100
\$400,000 - \$599,999	Low	90
\$600,000 - \$799,999	Below average	75
\$800,000 - \$999,999	Above average	33
\$1,000,000 - \$1,499,999	High	10
≥ \$1,500,000	Highest	0

Table 18. The additive utility values for each restoration measure and land acquisition option evaluated in the Bayesian Belief Networks (BBNs) for the Alabama Barrier Island Restoration Assessment. Restoration measures are sorted from the most optimal decisions to the least for structural measures and land acquisitions.

Structural Measures	Utility
East End Beach and Dune Restoration Opt-1	301.094
East End Beach and Dune Restoration Opt-2	301.094
East End Beach and Dune Restoration Opt-3	301.094
West End and Katrina Cut Beach and Dune Restoration (Voluntary Buyouts) Opt-1	231.122
West End and Katrina Cut Beach and Dune Restoration (Voluntary Buyouts) Opt-2	231.122
West End Beach and Dune Restoration (No Buyouts) Opt-1	229.213
West End Beach and Dune Restoration (No Buyouts) Opt-2	229.213
Marsh Habitat Restoration Behind Katrina Cut Opt-1	224.819
Marsh Habitat Restoration Behind Katrina Cut Opt-3	224.819
Aloe Bay Beneficial Use Marsh Restoration Opt-1	224.819
Aloe Bay Beneficial Use Marsh Restoration Opt-2	224.819
Pelican Island Southeast Nourishment Opt-1	221.878
Pelican Island Southeast Nourishment Opt-2	221.878
Sand Island Platform Nourishment and Sand Bypassing Opt-2	216.681
Marsh Habitat Restoration Behind Katrina Cut Opt-2	214.819
West End Beach and Dune Restoration (Voluntary Buyouts) Opt-1	213.411
West End Beach and Dune Restoration (Voluntary Buyouts) Opt-2	213.411
Pelican Island Southeast Nourishment Opt-3	211.878
Graveline Bay Marsh Restoration	209.819
2010 Borrow Pits Restoration Opt-1	206.819
2010 Borrow Pits Restoration Opt-2	206.819
Sand Island Platform Nourishment and Sand Bypassing Opt-1	206.681
Katrina Cut Structure Removal	195.939
West End Back-Barrier Herbaceous Dune Plant Restoration	181.974
Land Acquisition Measures	
Dauphin Island 39 Parcel Property Acquisition: Parcel B – Graveline Bay	142.200
Dauphin Island 39 Parcel Property Acquisition: Parcel D – Little Dauphin Island Bay	117.400
Dauphin Island 39 Parcel Property Acquisition: Parcel A – West End	104.700
Dauphin Island 39 Parcel Property Acquisition: Parcel C – Aloe Bay	100.900
West End Land Acquisition	100.000
Tupelo Gum Swamp Land Acquisition	92.400
Steiner Property Acquisition	92.400
Gorgas Swamp Land Acquisition	90.200
Dauphin Island 39 Acquisition: Parcel E – East End	81.500
Mid-Island Land Acquisition and Management Phase I	23.000
U.S. Coast Guard Property Acquisition	8.700

Appendix A. Expert elicitation documents for identification of habitat affinities for selected fauna of Dauphin Island, Alabama.

Alabama Barrier Island Restoration Assessment at Dauphin Island
Faunal Species Expert Elicitation
January 2017

Project Description: The Alabama Barrier Island Restoration Assessment at Dauphin Island project is a collaborative effort between the State of Alabama, the U.S. Geological Survey, and the U.S. Army Corps of Engineers funded by the National Fish and Wildlife Federation (NFWF) to investigate viable, sustainable restoration options that protect and restore the natural resources of Dauphin Island, including habitat and living coastal and marine resources, as well as protect the coastal resources of the Mississippi Sound/Mobile Bay and the southern portion of Mobile County including the expansive Heron Bay wetlands.

Scope: The scope of the project includes data collection and modeling and tool development to assess the current and future function of the island and evaluate the most resilient and sustainable restoration options in support of critical habitats and natural resources.

Potential Restoration Activity Examples: For context, a few possible restoration actions are listed below.

- Beach and dune restoration
- Marsh restoration
- Nearshore sand placement
- Sand bypassing
- Dredge holes restoration
- Land acquisition

Faunal Species Background: As mentioned previously, the restoration feasibility effort is focused on identifying resilient and sustainable restoration options in support of critical habitats and natural resources. Team members from the habitat modeling and alternative assessment task groups are working together to engage faunal experts to develop a faunal species list for the project and to estimate general linkages of faunal species to habitats being modeled by the project. In summer 2016, we developed a draft faunal species list using the State of Alabama

State Wildlife Action Plan. We engaged faunal experts with the goal of refining the list (i.e., adding, keeping, or removing species). The goal was to develop a final list that was exhaustive, and included species that were impacted by the Deep Water Horizon (DWH) oil spill along with species of interest for the State of Alabama and the broader region (i.e., U.S. Fish and Wildlife Threatened and Endangered Species). In September, we held a single-day workshop to begin the steps of developing linkages for faunal species and habitats. This document will provide information necessary to review, refine, and complete the elicitation initated in September. As work continues on this project, it is anticipated that we may have a need to connect with all experts or certain expert subgroups for additional input in the future, as needed.

Habitat Modeling Objective: Geospatial models will be developed to predict habitats in the future with the goal of identifying sustainable restoration options that protect and restore the natural resources of Dauphin Island. These models will be linked to the outputs of the geomorphologic and water quality models (i.e., other tasks in the Alabama Barrier Island Restoration Assessment at Dauphin Island project) to help quantify changes to habitats for proposed restoration alternatives. As discussed previously, an expert elicitation will be used to develop linkages for faunal species to modeled habitats. These data will help facilitate the assessment of specific restoration actions with regards to potential impacts (e.g., positive and/or negative) on faunal species.

Habitat Modeling Details: This project will include the modeling of twelve general habitats (Table 1A and Figure 1A). Two approaches will be used to model these habitats. The first approach will be to predict the future coverage of terrestrial habitats (i.e., intertidal and upslope habitats) using landscape position-based information (i.e., elevation, distance from shore, etc.) from geomorphologic model outputs. Where feasible, we will attempt to tease out additional details within these habitats, such as whether barrier flat habitat is more likely vegetated or unvegetated and/or to determine the proportion of woody vegetation that would likely be forested or scrub/shrub habitat. The second approach will be focused on developing simple habitat suitability index models for seagrass and estuarine intertidal oyster reef habitats, respectively, through the use of water quality model outputs and select geomorphologic model outputs (i.e., water depth, distance from shore).

Data used to predict habitat coverage will come from the geomorphic and water quality model outputs (i.e., these are other tasks conducted for the Dauphin Island project). The spatial resolution of the geomorphic model is a variable mesh with a minimum from ~ 2.5 m to a maximum of 40 m. The spatial resolution of the water quality model outputs range from 15 to 25 m in nearshore areas and up to 5 km in offshore areas. The temporal resolution of both the geomorphic and water quality model outputs could be as high as hourly. It is likely the outputs will be summarized for longer temporal intervals (e.g., daily, monthly, seasonally, or annually).

Table 1A. List of habitats for habitat modeling effort

Class	Description
Beach[1]	Bare or sparsely vegetated area that is found adjacent to waters of the Gulf of Mexico. Beach is located above the extreme high tide level (i.e., above intertidal beach or flat) and often transitions to barrier flat behind a beach a berm or dune.
Dune[1]	Dunes are supratidal features (e.g., found at a higher elevation level than the water level from intense storms as indicated by NOAA exceedance probability level surpassed 10 years out of 100). Dunes can either form linear ridges or be characterized by deflation hollows and parabolic or crescentic morphologies. This class includes primary dunes found at the beach-dune interface and secondary dunes that have migrated further inland. Relative elevation is the primary distinguishing feature of dunes.
Woody vegetation[1]	Includes all woody vegetation (i.e., shrubs and trees). Total woody vegetation coverage is greater than 20 percent.
Barrier flat[1]	Gently sloping supratidal (i.e., found above the extreme high tide level) portion of the island found behind the beach berm or dunes. These areas typically display no distinctive topographic pattern besides a gentle slope towards the back-barrier shoreline of the island. These flats can include vegetation or be unvegetated areas. Note: a separate effort is being developed to estimate a probability of a barrier flat to be vegetated based on landscape position and antecedent conditions.
Intertidal beach[1]	Bare or sparsely vegetated area located between extreme low tide and extreme high tides levels on the gulf-facing shoreline.
Intertidal flat[1]	Bare or sparsely vegetated area located between extreme low tide and extreme high tides levels on the back-barrier shoreline.
Intertidal marsh[1]	Includes all tidal areas dominated by erect, rooted, herbaceous hydrophytes that occur in tidal areas (i.e., between extreme low tide and extreme high tide) in which average annual salinity due to ocean-derived salts is equal to or greater than 0.5 parts per thousand (ppt).
Estuarine intertidal reef[2]	Intertidal estuarine ecosystems dominated by ridge-like or mound-like structures formed by the colonization and growth of extensive, exoskeleton-building sessile invertebrates. Reefs include areas that are subtidal, irregularly exposed, regularly flooded, and irregularly flooded. Reefs are characterized by their elevation above the surrounding substrate and their interference with normal wave flow. This also includes large deposits of rock that are elevated above the surrounding substrate and affects current flow.
Seagrass[2]	Any combination of seagrasses (i.e., seagrasses, oligohaline grasses, attached macroalgae, and drift macroalgae) that covers 10-100 percent of the substrate.
Open water, fresh[1]	All inland non-tidal open water in which average annual salinity is below 0.5 ppt. These areas will have less than 30 percent vegetative/substrate visible and less than 25 percent cover by vegetation.
Open water, estuarine[1]	All areas of open water extending to nearshore waters along the estuarine shoreline of the island. This class includes any water that is connected to offshore water through tides on both the estuarine and marine side of the island. These areas will have less than 30 percent vegetative/substrate visible and less than 25 percent cover by vegetation.
Open water, marine[1]	All areas of open water extending to nearshore waters along the gulf-facing side of island. These areas will have less than 30 percent vegetative/substrate visible and less than 25 percent cover by vegetation.

[1] Landscape position-based geoprocessing model using geomorphologic model outputs will be used to predict future habitat coverage

[2] Habitat suitability index models using outputs from water quality and bathymetric models (e.g., salinity, suspended solid, dissolved inorganic nitrogen and phosphorus (DIN and DIP), chlorophyll-*a*, water depth, and variability of these water quality parameters) will be used to predict future habitat coverage

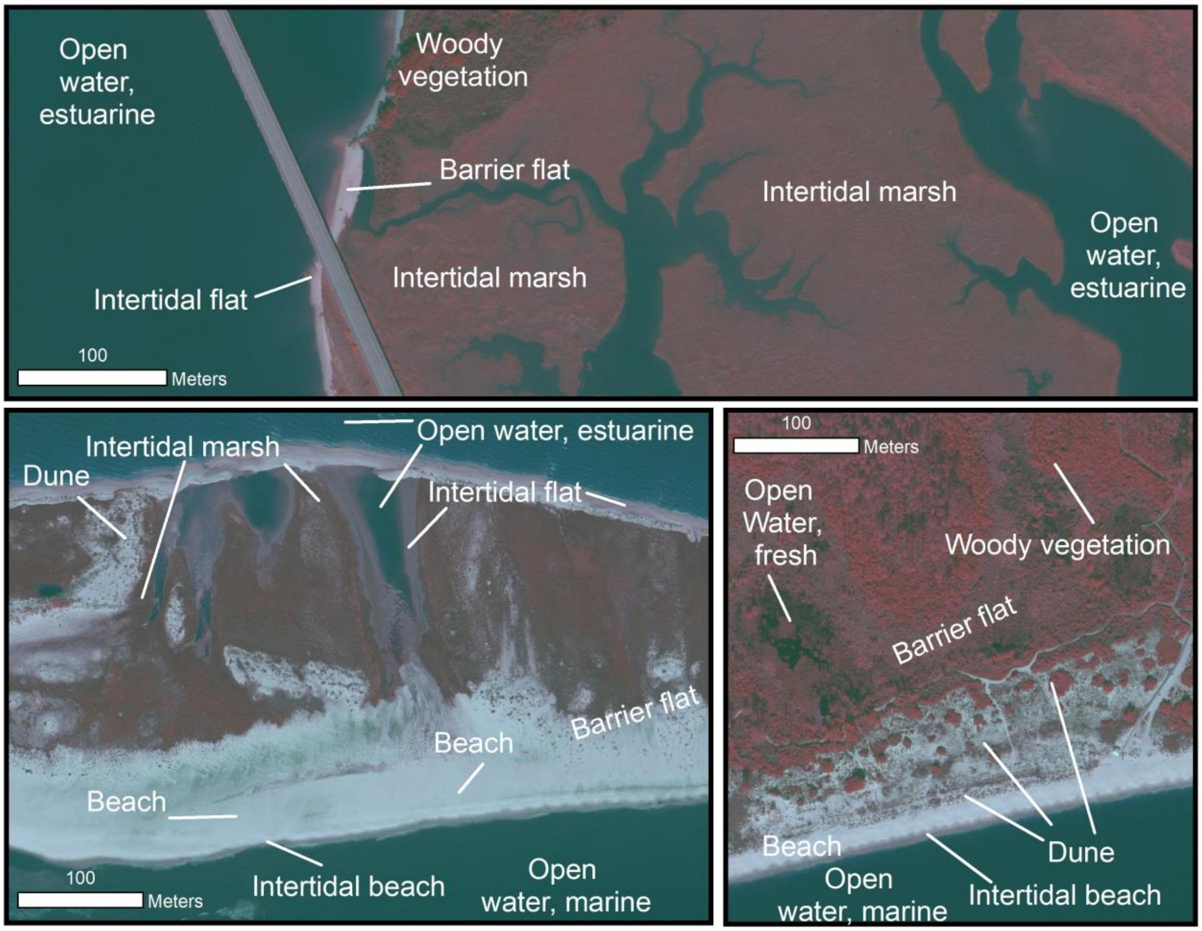

Figure 1A. Examples of habitats for habitat modeling effort.

Below is a list of types of variables that could be used to model habitats. These variables will either be directly obtained from geomorphic model outputs or water quality model outputs or could be estimated from geomorphic model outputs. Given the type of information available for the habitat modeling effort, it is important to point out that we will not have sufficient information to predict specific habitat conditions such as understory structure in forested areas.

Types of variables that could be used to model habitats:

- Elevation
- Slope
- Distance from shoreline
- Elevation relative to tidal datum
- Inundation frequency
- Water depth
- Benthic disturbance index
- Relative exposure index
- Water quality

Elicitation Worksheet:
We have developed a Microsoft Excel spreadsheet to capture expert opinion on how important (i.e., "Utilization value") each habitat is to each faunal species (i.e., linkages of faunal species to habitats being modeled). Below is a breakdown of the tabs and contents of the habitat linkage worksheet.

1) Eight tabs for different guilds/species for input (Figure 2):
   - Shorebirds,
   - Neotropical migrants,
   - Other birds,
   - Reptiles & amphibians,
   - Crayfish,
   - Fish & crustaceans,
   - Sea turtles,
   - Marine mammals

2) A tab with Class descriptions and examples

On each tab there is a column for species that were identified as being impacted by the DWH oil spill or species of interest for the State of Alabama or broader geographic area. For each species, each habitat has an importance ranking (i.e., how important is this habitat for the species) and a "specific comments" field. The type of information we are looking for in the specific comments blank is whether the importance value is specific to a sub habitat (e.g., only tidal ponds) or may be different for subhabitats within the general habitat type. A few examples of "specific comments" include:

- For Woody vegetation: If forested, the value would be 5; if scrub/shrub, the value would 4.
- For Barrier flat: If vegetated, the value would be 1; if vegetation status is unknown, the value would be 3; or if unvegetated the value would be 5.
- Pertains only to scrub/shrub
- Pertains only to intertidal ponds
- Etc.

Table 2A. List of species for habitat affinity determination by experts.

Group	Species	Group	Species
Shorebird	Least tern	Fish & crustaceans	Fiddler crab
Shorebird	Piping plover	Fish & crustaceans	Brown shrimp
Shorebird	Snowy plover	Fish & crustaceans	White shrimp
Shorebird	Wilson's plover	Fish & crustaceans	Pink shrimp
Shorebird	Oystercatcher	Fish & crustaceans	Gulf sturgeon
Shorebird	Gull-billed tern	Sea turtles	Loggerhead
Shorebird	Red knot	Sea turtles	Green
Shorebird	Black skimmer	Sea turtles	Kemp's Ridley
Neotropical bird	Cerulean warbler	Sea turtles	Leatherback
Neotropical bird	Swainson's warbler	Sea turtles	Hawksbill
Neotropical bird	Gold-winged warbler	Marine mammals	Common bottlenose dolphin
Other bird	Seaside sparrow	Marine mammals	West Indian manatee
Other bird	Nelson's sparrow		
Other bird	Reddish egret		
Other bird	Least bittern		
Other bird	Loggerhead shrike		
Other bird	Short-billed dowitcher		
Other bird	Western sandpiper		
Other bird	Stilt sandpiper		
Other bird	Mottled duck		
Other bird	Gulls		
Other bird	Little blue heron		
Other bird	Brown pelican		
Reptile & amphibian	Smallmouth salamander		
Reptile & amphibian	Southeastern five-lined skink		
Reptile & amphibian	MS diamondback terrapin		
Reptile & amphibian	Gulf marsh snake		
Reptile & amphibian	Eastern coral snake		
Reptile & amphibian	Eastern diamondback rattlesnake		
Reptile & amphibian	Eastern kingsnake		
Crayfish	Least crayfish		
Crayfish	Angular dwarf crayfish		
Crayfish	Cajun dwarf crayfish		
Crayfish	Speckled burrowing crayfish		
Crayfish	Panhandle crayfish		
Crayfish	Mobile crayfish		

	Utilization Value (0 [lowest] - 5 [highest])							
	Least terns	**Piping plovers**	**Snowy plovers**	**Wilson's plover**	**Oystercatchers**	**Gull-billed terns**	**Red knots**	**Black skimmers**
Beach	5	5	5	5	5	5	5	5
Specific Comments	None	None	None	None	None	None	None	None
Dune	5	5	5	5	0	5	5	5
Specific Comments	None	None	None	None	NA	None	None	None
Woody vegetation	0	0	0	0	0	0	0	0
Specific Comments	NA	NA	NA	NA	NA	NA	NA	NA
Barrier flat	1;3;5	1;3;5	1;3;5	5	0	1;3;5	1;3;5	1;3;5
Specific Comments	If vegetated - 1; if vegetation status is unknown - 3; if unvegetated - 5	If vegetated - 1; if vegetation status is unknown - 3; if unvegetated - 5	If vegetated - 1; if vegetation status is unknown - 3; if unvegetated - 5	None	NA	If vegetated - 1; if vegetation status is unknown - 3; if unvegetated - 5	If vegetated - 1; if vegetation status is unknown - 3; if unvegetated - 5	If vegetated - 1; if vegetation status is unknown - 3; if unvegetated - 5
Intertidal beach	0	5	5	5	5	0	5	0
Specific Comments	NA	None	None	None	None	NA	None	NA
Intertidal flat	0	5	5	5	5	0	5	0
Specific Comments	NA	None	None	None	None	NA	None	NA
Intertidal marsh	0	0	0	0	0	5	0	0
Specific Comments	NA	NA	NA	NA	NA	None	NA	NA
Estuarine intertidal reef	0	0	0	0	0	0	0	0
Specific Comments	NA	NA	NA	NA	NA	NA	NA	NA
Seagrass	0	0	0	0	0	0	0	0
Specific Comments	NA	NA	NA	NA	NA	NA	NA	NA
Open water, fresh	5	0	0	0	0	0	0	0
Specific Comments	None	NA	NA	NA	NA	NA	NA	NA
Open water, estuarine	5	0	0	0	0	5	0	5
Specific Comments	None	NA	NA	NA	NA	None	NA	None
Open water, marine	5	0	0	0	0	5	0	5
Specific Comments	None	NA	NA	NA	NA	None	NA	None

Figure 2A. Faunal species habitat linkage worksheet.

Instructions for elicitation:

1. Use professional judgement to develop importance values for each habitat for each species/guild for only the tabs you feel comfortable providing data for. If input has already been provided for species please review input. If you disagree with the current values/content please provide suggested edits with rationale as a comment in the specific cell using the comment feature on the Review tab in Excel.
2. Provide any specific comments (see examples on page 5).
3. If you have any questions please contact Elise Irwin (eirwin@usgs.gov; 337-884-9234 or Nicholas Enwright enwrightn@usgs.gov; 337-852-7134)

Please send completed worksheet to Elise Irwin (eirwin@usgs.gov) by February 28, 2017

Table 3A. Results from expert elicitation for ecosystem services provided by habitats associated with Dauphin Island and its associated ecosystem. Experts used different colored 'sticky notes' to assign individual services to habitat descriptions. A tally score (count of votes) indicated the ecosystem services most frequently identified as important by experts. The different color x in the table indicate different expert's input; some experts had the same color sticky notes.

Elicited Information	Maritime Forest	Submerged Aquatic Vegetation	Freshwater Wetland	Streams/ Riparian Buffer	Interidal Marshes/Flats	Beaches/ Dunes	Oyster Reefs	Counts
Ecological Function/Ecosystem Services								
Biodiversity	xx	xxxx	x	xx	xxxxx	xx	xxxx	20
Ground Water Recharge	x		x	xx				4
Carbon Sequestration	x		x	x	x			4
Sediment/Nutrient Retention & Transport	x	xxxxx	xx	x	xxxxx	xxxx	xx	20
Water Quality Enhancement	x	xxxx	xxx	x	xxxxxx	x	xxxxx	21
Storm Buffer/Hazard Protection	xx	x	x		xxxx	xxxxx	x	14
Chemical Processes	x	x	x	x				4
Erosion Control					x			1
Flood Control			xxx		xx			5
Fisheries Habitat		xxxxx	xxx	xx	xxxx		xxxx	18
Primary Production		xxx	x		x		x	6
Benthic Habitat		x						1
Oyster & Fisheries Production		x			x		xxxxx	7
Nesting Habitat for Turtles				x	x	xxxxxxx		9
Nesting Habitat for Birds	xx		x	x	xx	xxxxx		11
Nursery							x	1
Migratory Stopover for Neotropical Migrants	x							1
Recreation & Tourism					x		xx	3
Wildlife Habitat	xx	x	xxx	xx	xxx	x		12
Sub_Habitat								
Xeric Oak Hammock	x							1
Cattails (aquatics)			x					1
Elevation					xx	x		3
Sand Volume					x			1
Plant Density					x			1
Washover/Washthru						x		1
Width						x		1
Longshore Uniformity						x		1
Slope						x		1
Overwash Frequency						xx		2
Vegetation						x		1
Migratory Stopover Area for Neotropical Migrants	x							1
Cultural Resources								
Cultural Resources	x							1
Shell Middens	xx							2
Human Use								
Human Use			x			xxx	xx	6
Birding	x							1
Commercial Use							x	1

Table A3. Continued.

Valued for Human and fauna								
1º ECO/2º Human	×		×			×		3
Human & Species: Various	×	×	×	×	×	××	×××	11
Fauna								
Rodents						×		1
Keystone Species							×	1
Benthos			×					1
Plankton			×					1
Aquatic Snakes			×					1
Aquatic Salamanders			×					1
Frogs/Toads			×					1
Totals	21	27	30	15	42	40	34	

Table 4A. Results from literature and expert elicitation for habitat affinities for species considered important on Dauphin Island. Habitat affinity was scored on a Likert scale (0-5) where 0 represented limited use of the habitat and 5 represented the highest habitat affinity for the species. These data were used in the non-metric multidimensional scaling (NMDS) analysis.

Species	Group	Beach	Dune	Woody vegetation	Woody wetland	Barrier flat	Intertidal beach	Intertidal flat	Marsh	Seagrass	Water fresh	Water estuarine	Water marine
Least tern	Shorebird	5	5	0	0	5	0	0	0	0	5	5	5
Piping plover	Shorebird	5	5	0	0	5	5	5	0	0	0	0	0
Snowy plover	Shorebird	5	5	0	0	5	5	5	0	0	0	0	0
Wilson's plover	Shorebird	5	5	0	0	5	5	5	0	0	0	0	0
Oystercatcher	Shorebird	5	2	0	0	0	5	5	3	0	0	0	0
Gull-billed tern	Shorebird	5	5	0	0	5	0	0	5	0	0	5	5
Red knots	Shorebird	5	5	0	0	5	5	5	3	0	0	0	0
Black skimmer	Shorebird	5	5	0	0	5	0	0	2	0	0	5	5
Cerulean warbler	Neotropical bird	1	1	5	4	1	0	0	2	0	2	0	0
Swainson's warbler	Neotropical bird	1	1	5	4	1	0	0	2	0	2	0	0
Gold-winged warbler	Neotropical bird	1	1	5	5	1	0	0	2	0	2	0	0
Seaside sparrow	Other bird	0	0	3	1	0	0	4	5	0	0	0	0
Nelson's sparrow	Other bird	0	0	0	0	0	0	4	5	0	0	0	0
Reddish egret	Other bird	0	0	1	1	0	0	5	2	0	0	3	0
Least bittern	Other bird	0	0	2	4	0	0	4	5	0	0	1	0
Loggerhead shrike	Other bird	0	0	5	4	0	0	0	0	0	0	0	0
Short-billed dowitcher	Other bird	5	0	0	0	0	5	4	0	0	0	0	0
Western sandpiper	Other bird	5	0	0	0	0	5	4	0	0	0	4	0
Stilt sandpiper	Other bird	5	0	0	0	0	5	4	0	1	0	0	0
Mottled duck	Other bird	2	2	0	0	0	0	0	5	0	3	4	0
Gulls	Other bird	4	2	3	1	0	4	0	2	0	0	5	5

Table 4A. Continued.

Little blue heron	Other bird	0	0	2	4	0	0	4	5	0	4	0	0
Brown pelican	Other bird	4	2	3	2	0	4	0	0	0	0	5	5
Smallmouth salamander	Reptile & amphibian	0	0	5	5	0	0	0	0	0	5	0	0
Southeastern five-lined skink	Reptile & amphibian	0	0	5	5	0	0	0	0	0	0	0	0
MS diamondback terrapin	Reptile & amphibian	0	0	0	1	0	0	0	5	0	0	4	0
Gulf marsh snake	Reptile & amphibian	0	0	0	1	0	0	3	5	0	0	3	0
Eastern coral snake	Reptile & amphibian	0	0	4	2	0	0	0	1	0	0	0	0
Eastern diamondback rattlesnake	Reptile & amphibian	0	3	5	4	3	0	0	0	0	0	0	0
Eastern kingsnake	Reptile & amphibian	0	3	5	4	3	0	0	0	0	0	0	0
Least crayfish	Crayfish	0	0	1	4	0	0	0	1	0	5	0	0
Angular dwarf crayfish	Crayfish	0	0	1	4	0	0	0	1	0	5	0	0
Cajun dwarf crayfish	Crayfish	0	0	1	4	0	0	0	1	0	5	0	0
Speckled burrowing crayfish	Crayfish	0	0	1	5	0	0	0	1	0	5	0	0
Panhandle crayfish	Crayfish	0	0	1	5	0	0	0	1	0	5	0	0
Mobile crayfish	Crayfish	0	0	1	4	0	0	0	1	0	5	0	0
Fiddler crab	Fish & crustaceans	3	5	5	5	5	2	2	5	3	1	5	4
Brown shrimp	Fish & crustaceans	0	0	0	0	0	0	0	4	4	0	5	5
White shrimp	Fish & crustaceans	0	0	0	0	0	0	0	4	4	0	5	5
Pink shrimp	Fish & crustaceans	0	0	0	0	0	0	0	4	4	0	5	5
Gulf sturgeon	Fish & crustaceans	0	0	0	0	0	3	3	0	0	2	4	4
Loggerhead	Sea turtles	5	5	0	0	0	3	0	4	5	0	5	5
Green	Sea turtles	3	3	0	0	0	3	0	4	5	0	5	5
Kemp's Ridley	Sea turtles	1	1	0	0	0	3	0	4	5	0	5	5
Leatherback	Sea turtles	3	3	0	0	0	0	0	0	0	0	5	5
Hawksbill	Sea turtles	3	3	2	2	0	0	0	0	0	0	5	5
Common bottlenose dolphin	Marine mammals	0	0	0	0	0	0	0	0	2	0	3	5
West Indian manatee	Marine mammals	0	0	0	0	0	0	0	2	5	0	5	2

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